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NUCLEONICS

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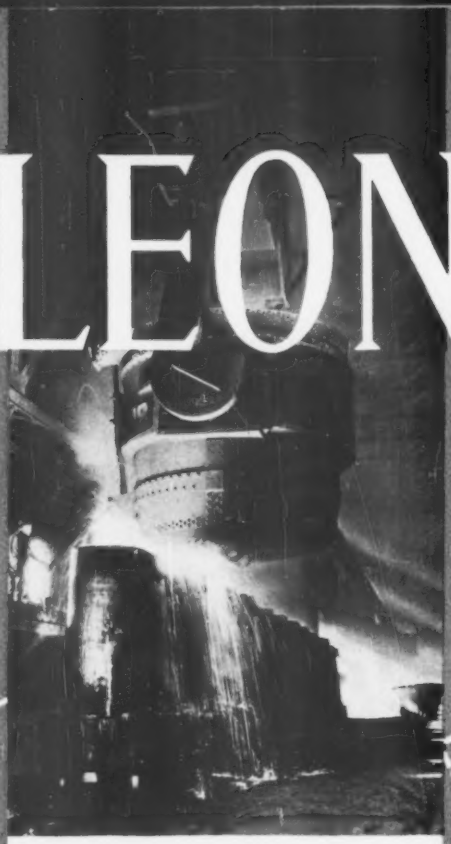

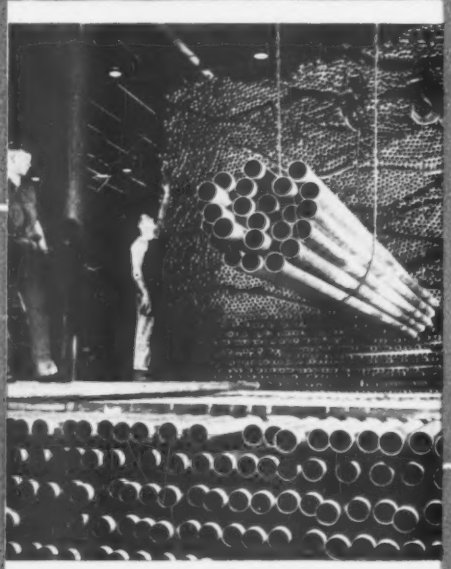

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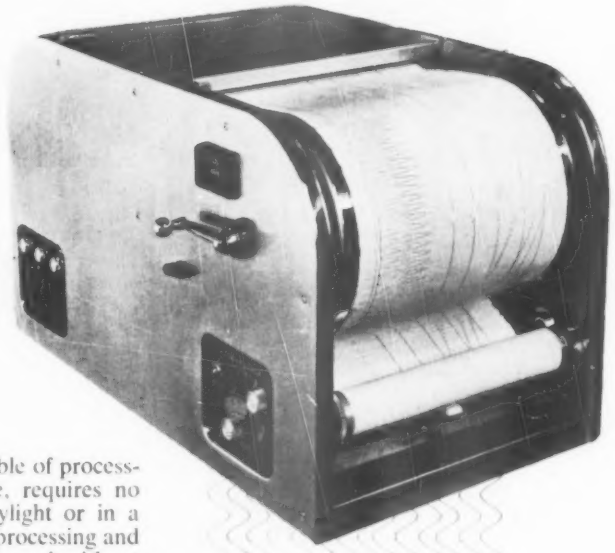

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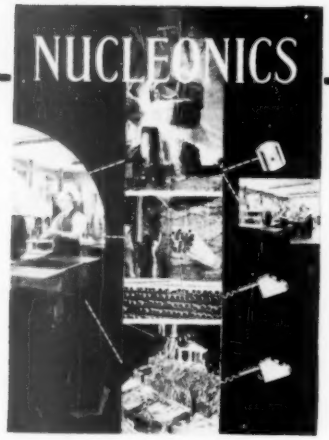

JANUARY • 1954

Vol. 12, No. 1

British Developments in Atomic Energy... 6
SIR CHRISTOPHER HINTON

Reorganize British Atomic Program... 7

International Commission Recommendations:
Radiological Units... 11

Plans For the New Argonne Research Reactor, CP-5... 12
S. UNTERMYER

Radioactive Tracers for Tagging Special Steel Melts... 16
DAVID L. DOUGLAS

Simplified Autoradiography Exposure Calculation... 19
W. W. WAINWRIGHT, E. C. ANDERSON, P. C. HAMMER, and C. A. LEHMAN

Kinetic Behavior of a Thermal Heavy-Water Reactor... 22
A. LUNDBY and N. HOLT

The New Radiometallurgy Laboratory at Hanford... 26

Effect of X-Irradiation on Tissue Hydration in the Mouse... 28
ROBERTS RUGH

Gamma-Ray Scintillation Counter for Weak Radioactive Solutions... 34
C. P. HAIGH

Analysis of Radiation Fields of Two Gamma-Radiation Sources... 40
JOHN G. LEWIS, JOHN V. NEHEMIAS, DAVID E. HARMER, and JOSEPH J. MARTIN

Discontinuous Servo for Control of Power Reactors... 44
J. M. HARRER and J. A. DESHONG, Jr.

Evaluating the Safety of Radiation-Sterilized Foods... 52
A. J. LEHMAN and E. P. LAUG

The Best Performance From Beta Gages... 55
L. R. ZUMWALT

Cross Sections

Electric Recorder for the Gammagraph... 60
MARTIN E. JACOBS, ALAN L. ORVIS, and BERNICE B. BORRMAN

Solid-Sample Beta Determinations with a Liquid Scintillation Counter... 61
F. TERENTIUK

Go, No-Go Radiation Detector... 62
H. D. LeVINE

Measurement of Breath Radon by Charcoal Adsorption... 62
JOHN B. HURSH

Nuclear Engineering

Reactor Designs for Commercial Power... 66
J. R. MENKE

Survey of Radioactive Waste Disposal Practice... 68
H. S. MILLER, F. FAHNOE, and W. R. PETERSON

Departments

EDITORIAL..... 5
LETTERS..... 59
BOOKS..... 70
NEWS..... 72
PRODUCTS AND MATERIALS... 78

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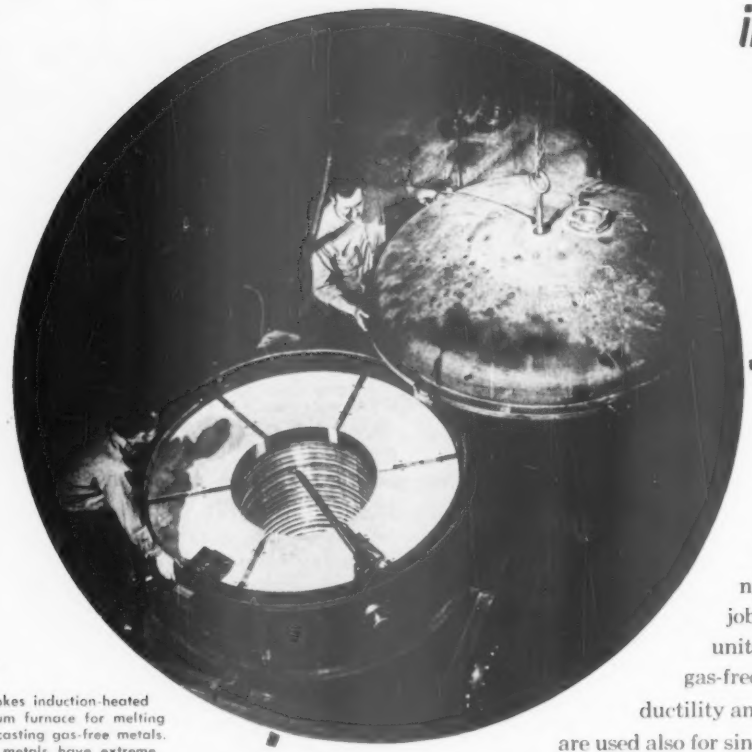

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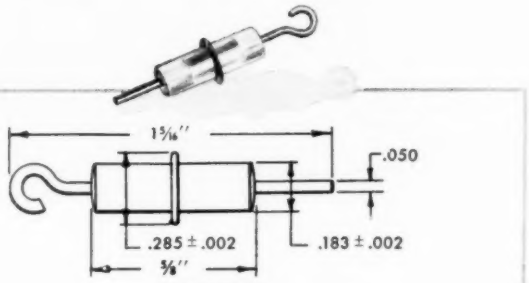

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GENERAL ELECTRIC

NUCLEONICS JANUARY, 1954

Jerome D. Luntz, *Editor*

Time for Boldness

SOMETIME IN JANUARY Congressman W. Sterling Cole, chairman of the Joint Committee on Atomic Energy, is scheduled to introduce in Congress a bill proposing major amendments to the Atomic Energy Act of 1946. Shortly thereafter about six weeks of public hearings will be held. Mr. Cole expects that a final version of the bill will be reported out of his committee by late spring of 1954.

Despite the fact that a bill will be introduced recommending changes in the law permitting industry to work in the reactor field, there is still some disagreement on whether this is the time for such changes to be made.

In the hearings before the Joint Committee last summer, industry was singularly disunited in its over-all position and particularly lax in presenting a strong case for the need for a change *now*. The fate of the proposed amendments may rest on the merits of arguments on this last point.

Although there are many reasons why the law should be changed now, Congressmen still ask industry this one question: "How much money is your company prepared to put up?" They bring it down to the level of "put up or shut up."

WE AREN'T CONVINCED that this is a logical basis for decision on such crucial legislation. But the realities of life should be faced. We believe industry is in a position to "put up" and that it should do so before the conclusion of the forthcoming hearings. The impact on the Congress of such an action would be considerable.

There are three possible ways that industry can "put up." By announcing:

1. That it wants to build a full-scale plant.
2. That it wants to build a pilot plant.
3. That it wants to build a "package" reactor.

Although it appears quite likely that, legislation permitting, some one industrial group will be ready to invest its own money in a full-scale plant within the next year or two, it is highly unlikely that this will happen within the next several months. This would eliminate the first possibility above.

Both the second and third seem to be quite possible as far as the ability of a group to line up the necessary funds is concerned, but the second is quite controversial from the point of view of technical desirability.

THE MOST PLAUSIBLE may be the third—package reactors. Some advocate this as the best route to economic nuclear power under any circumstances. But our purpose here is not to suggest a "best" plan but rather to suggest a means for getting this industry going, a means to assure legislative action.

An analysis (NU, April '53, p. 32) of the market for high-cost "package" nuclear power showed that there are a number of very interesting markets at various military installations (e.g., Thule Air Base, Greenland, now pays 4¢/kwh for power). It is predicted by many that reactors to produce say 5,000 kw to serve such needs could be built for $3–5-million, with the power costing perhaps 2½–4¢/kwh.

Thus it would seem quite feasible for a group of companies to raise the money for such a project. This group might then say to the Joint Committee on Atomic Energy: "We have $*X*-million that we'd like to use to build a small power reactor at some U. S. military installation. We'll operate the reactor and sell the power to the military at an agreed unit price. Maybe we'll make a profit. Maybe we won't. What's important is that we'll get the experience, the know-how. We'll train men. Most importantly, we want you to know that industry is seriously interested in the atomic energy industry."

Could the Congress turn its back on such a proposal? We don't think so.

British Developments in Atomic Energy

SIR CHRISTOPHER HINTON, Deputy Controller, Atomic Energy (Production), Ministry of Supply, London, answers these and other questions. . . .

Who does the actual work in development of atomic energy in Britain? Why?
What progress has been made, and what is the pattern of future development?
When will British industry enter the nuclear power field?
Why is reactor safety the biggest problem facing industrial nuclear power?

While the British atomic energy organization was set up in the spring of 1946, I think it would be a mistake to imagine that, on peacetime standards, you in the United States had only a three years' lead over us. A great deal of the early scientific work had been done in England and, prior to 1943, there had been some study of industrial implications. But in that year, it was agreed between your President and our Prime Minister that the whole of the research and production work aimed at the production of the atomic bomb should be done in America. Three years of intensive, high priority development work in time of war, when great industrial firms can be persuaded to turn their resources into a new project, and when it can reasonably absorb a higher proportion of the national resources than would be acceptable in time of peace, is worth a great deal. In terms of postwar conditions I suggest that you had an advantage of something like six years over us.

During those wartime years, the big industrial organizations that did such magnificent work in the production of fissile material had obtained an experience of and interest in atomic energy, which must have made it easy to persuade many of them to continue their work after the end of the war. We were in a very different position; no British firm had an established stake in atomic energy, and I need not remind you that in 1946, British industry was passing through a very difficult period. Its resources were fully occupied in turning back from war to peace production and in building up the exports that were a national necessity.

Two Different Systems

Largely as a result of these conditions, the British atomic organization was forced to adopt a different form from that which you have adopted in the United States. As I understand it, your organization formulates policy and directs operations, but the execution of work, whether on research, on design and construction of factories, or in their operation, is carried out for you by contractors. Our British organization, on the other hand, itself carries out most of its own research work and virtually all of its own design, construction and operation.

It is worth while to look at the relative advantages and disadvantages of the two systems. I suggest that ours has given us a closely coordinated organization in which every branch is well aware of the work going on in other departments. Because of this I feel that the organization has been economical in its use of staff and has achieved results that would have demanded a greater effort had the work been dispersed. This is no small advantage when one remembers the limited effort possible under our rather strained economic conditions.

The disadvantage of our organization is that it has thrown a very heavy load on the senior members of the staff. Under your system you were

(Continued on page 8)

Reorganize British Atomic Program to Improve Finances, Add Impetus to Long-Range Nuclear Power Development

LORD SALISBURY, head of new Atomic Energy Corporation described on this page, has held many high government posts, including Acting Foreign Minister

LONDON (*McGraw-Hill World News*): On January 1, responsibility for atomic energy development in Britain passed from the Ministry of Supply (MoS) to a new, relatively autonomous government unit called the Atomic Energy Corporation (BAEC). This "crown corporation" will be headed by Lord Salisbury (above), who, as Lord President of the Council, can be compared to a cabinet minister without portfolio. The significance of his appointment is that ultimate responsibility for atomic energy policy will rest right at the top of the British Cabinet.

While the immediate reason for establishing BAEC is to make possible large capital spending over many years, the long-range objective is to hasten development of industrial nuclear power to replace Britain's dwindling coal reserves. Indications are that specific policies have not been worked out yet—while responsibility shifted from MoS on January 1, legislation bringing BAEC into being won't reach Parliament until this spring.

In the article on the facing page, Sir Christopher Hinton outlines the pattern atomic energy developments will probably follow. The pioneering work thus far done by MoS will be carried on by BAEC. But MoS will remain responsible for providing atomic weapons for the British armed services, with BAEC handling weapons production and research under contract.

The new corporation thus will be able to concentrate on its primary objective, developing nuclear power and handing out atomic developments for exploitation by British industry. Long established practices of MoS in other fields indicate that great use will be made of "development contracts." These allow industry, financed by Government, to exploit results of Government research. Government takes a royalty on all sales, but legal ownership of the product design rests with the company receiving the development contract.

Large-scale use of such contracts is a long way off. First purpose of BAEC in the industrial field will be to "get on" with two pilot power plants and to initiate projects towards Britain's second major atomic objective: the production of specialized nuclear power units for such purposes as ship propulsion. Of this second objective, no information at all is available at this time.

One pilot power plant is slated to be built at Cumberland. It will be a 40,000-kw unit with a graphite-moderated, CO_2-cooled reactor. The second, to be built around a "breeder" reactor, will probably be built in the extreme north of Scotland. But the site has not been chosen, and no design details have been released.

If the Cumberland plant is successful, chances are that the nationalized British Electricity Authority will buy power there for the national grid.

The Authority would be BAEC's first nonmilitary customer. And if this reactor type proved to be the best for the first commercial power plants, the Authority would be invited to build its own stations.

Pointing BAEC towards this objective, as chairman and managing director under Lord Salisbury, will be Sir Edwin Plowden, an experienced civil servant who during the war was chief executive of the Ministry of Aircraft Production. There will be four full-time directors of BAEC: one responsible for engineering and production; one for research; one for weapons; one for administration and finance. At this writing, appointments have not been made, but three at least are foregone conclusions. Sir Christopher Hinton is sure to be director in charge of production; Sir John Cockcroft for research; and Sir William Penney for weapons. These three currently hold the same posts under MoS.

Finally, there will be two part-time directors—perhaps ultimately three—without special technical functions. These will probably be civilian appointees, analogous to members of the U. S. Atomic Energy Commission.

Lord Salisbury, in a recent speech before Parliament, estimated that BAEC would spend $28-million a year at the outset. —END

able to call into operation the established staffs of large industrial companies; we, on the other hand, have had to build up our staffs from nothing.

Later on I shall be speaking of our plans for the future and I shall be saying that as we develop reactors for the production of industrial power, we shall expect to be providing the necessary information that will enable large industrial firms to continue the development of these reactors. Thus, in three or four years' time, we shall hope to have an organization that does the pioneering work for atomic energy, and having pioneered developments, hands these out to industry for manufacture on a wider scale, expecting industry to make the further developments that always become possible with growing operational experience.

I think that such an organization has a great deal to recommend it. I believe that we may well be pleased that we have developed along these lines and that we shall feel that the organization we have built up is the most suitable for our requirements.

First Stages

Let us then look at what has been done by this organization in the years since 1946.

The first step taken was to build up the research organization under Sir John Cockcroft at Harwell. This organization is engaged in long-term research and in devising the processes to be used in the industrial factories. It also does a considerable amount of applied research in aid of these industrial processes, but the Production Division itself has a Research and Development Section that does most of the necessary chemical engineering and other development work for translation of Harwell flowsheets into industrial designs.

The Production Division, for which I am responsible, was formed early in 1946, a little later than Harwell. Since then it has designed and constructed the large Harwell experimental reactor that was put into operation early in 1948.

Simultaneously with the construction of the Harwell experimental reactor, the production organization was engaged in building its factory at Springfields for conversion of uranium ore into canned uranium metal slugs. The processes used had been developed for the British government by Imperial Chemical Industries during the war and follow well known chemical principles.

Safety vs Reactor Type

Initially our intention was to build water-cooled graphite-moderated reactors; these reactors would have been similar in principle to your Hanford reactors. The water-cooled graphite-moderated reactor has a serious disadvantage in that like all reactors where the coolant has a neutron absorption capacity that outweighs its effect as a moderator, it can, under unfavorable circumstances, explode and scatter dangerous fission products over the countryside.

In America you were able to deal with this problem by building your reactors in a sparsely populated remote area where little disturbance would be caused in the unlikely event of an accident. In Great Britain we have far fewer thinly populated areas, and the choice of a site on which we could safely operate water-cooled reactors presented us with considerable difficulty. It was because of this that we decided to build air-cooled reactors for the production of plutonium.

The air-cooled reactor has many disadvantages as compared with the water-cooled reactor. Built under similar site conditions, it is appreciably more expensive in capital cost. It is more costly to operate because of the heavy expenditure on electric power required by the blowers. The quantity of graphite required as moderator in the core is greater, and the lock-up of uranium in the reactor is much heavier.

We felt, and I am sure that in our case it was true, that all of these disadvantages were outweighed by the fact that the air-cooled graphite-moderated reactor is inherently safe, and by adopting this type of reactor we were able to build our factory on the Cumberland coast, using an already developed site that was not so remote as to be inconvenient. The first of the two reactors built in this factory was in operation rather less than $3\frac{1}{2}$ years after the site was chosen.

Chemical Processing

At this factory we have also the chemical plants for extraction of plutonium and uranium from irradiated metal. It was decided at a fairly early date that we ought to adopt solvent extraction processes for these chemical separations, not merely because we wished to achieve the high efficiencies of which they are capable, but also because we felt that it was essential to adopt from the outset chemical processes that enabled us to recycle the uranium and secure economy in its use.

Construction of the chemical separation plants started late in 1948 on the basis of research at the Chalk River Laboratories (Canada) by Dr. Spence, who is now Head of the Chemical Engineering Division at Harwell. This research was done on only 20 milligrams of plutonium. As there was no time for a pilot or semitechnical plant before construction work started, we went into the full-scale construction of the very large and quite costly primary separation plant on the basis only of Dr. Spence's research carried out on so small a quantity of plutonium. It is, of course, not difficult to scale up a chemical process in this way if the full-scale process is to operate batchwise, but in this case we were scaling up from laboratory bench work to a continuous process. Also, the results of chemical engineering research on the more difficult sections of the plant became available to the designers only after construction was well under way. In spite of this, the plant went into operation on the programmed date, virtually without trouble.

It is interesting that this has been a frequent experience with our atomic energy chemical plants. Before the war I would very much have doubted the ability of any chemical plant design organization to build plants operating entirely new processes satisfactorily without first obtaining experience with pilot plants. Although we have one notable exception where we experienced considerable trouble in starting up a full-scale plant in the absence of pilot work, it has generally been our experience that plants which we design without waiting for the operation of a pilot plant give less trouble than one would normally expect. I believe, in the light of my experience over the last six years, that the construction of pilot plants is not an unmixed blessing. There is a tendency for the pilot-plant designer to take the line that he need not be too particular in his design because he is, after all, designing only a pilot plant. When the work is picked up by the designer of the full-scale plant, there is a tendency to argue that although the pilot plant looked in-

elegant, it has at least worked, and therefore it would be unwise to make modifications. If design work is put in hand without the construction of the pilot plant, the designer really has to think for himself.

Early in 1950, it was decided to proceed with the construction of a gaseous diffusion plant for the manufacture of uranium slightly enriched in the fissionable 235 isotope. This plant was necessary for re-enrichment of the purified uranium separated from the irradiated slugs in the chemical plant at Windscale and made available for recycling through the piles. The plant was built at Capenhurst in Cheshire and started operation early this year. Meanwhile, however, it had been decided to build alongside it a plant for the manufacture of highly enriched uranium, and construction work on this plant is now well in hand.

Current Power Reactors

We have recently started to construct a thermal reactor from which power will be produced in industrial quantities, and we expect shortly to be starting to build a fast reactor.

The power-producing thermal reactor is of a type long discussed; the reactor is graphite moderated and is cooled by circulating carbon dioxide under pressure. The reactor core is therefore enclosed in a mild steel shell within the biological shield; the boilers are arranged round it and supply steam to a turbogenerator plant of conventional design. We should have preferred helium as a coolant, but as helium supplies for this purpose were not available, we had to adopt the alternative of CO_2, which has comparatively minor disadvantages.

We hope that we shall be generating electric power that will be fed into the grid system of the country within the next few years.

Need for Industrial Power

The urgency for building up the industrial application of atomic energy for power production is, of course, greater in England than in the United States. Estimates for reserves of coal are never completely reliable, but it is probable that the reserves of easily workable coal in Great Britain will last only about 200 years. This is a comparatively short time in the industrial history of a country, and it must be remembered that coal is needed not merely for heating and power production, but also as an essential chemical and as a fuel in the metallurgical industry. It is therefore desirable that we should find a substitute for coal as a power-producing fuel as soon as is reasonably possible. It should, moreover, be remembered that with passing time it is the more easily workable seams that become exhausted; for this reason the price of coal in terms of real values is likely to increase as it has done in the past. The Ridley Committee, which recently investigated the fuel supply of Great Britain, gave figures suggesting that the deficit of coal mined against the coal required may amount to 20,000,000 tons in 1965.

A cost analysis does not suggest that the price of electricity generated from atomic energy will make it uncompetitive. Our present estimates show that it should be possible to generate electricity from gas-cooled thermal reactors at a price not greatly in excess of the cost of generation in a modern conventional power station. The latest figures of the British Electricity Authority show that the average cost of electricity to industry in 1951–52 was 1.002 pence per unit, as compared with a cost of 0.948 pence per unit in the previous year. The increase is partly a reflection of the increase in the price of fuel, the cost of which rose from 0.3932 to 0.4276 pence between 1950 and 1952, per unit of electricity. As I have already stated, this rising trend is likely to continue. It is, however, reasonable to believe that the

American View of Reactor Safety

HENRY D. SMYTH, *member of the U. S. Atomic Energy Commission, made these comments on Sir Christopher's views of reactor safety as a problem:*

Essentially I agree with what Sir Christopher has said, but I would like to put a little different emphasis on some aspects.

First of all, let me talk about the Hanford reactor, which he has mentioned specifically as inherently dangerous. He suggests that such a reactor as the one at Hanford "can, under unfavorable circumstances, explode and scatter dangerous fission products over the countryside." . . . . I would say "under an improbable combination of unfavorable circumstances" the reactor might explode.

Sir Christopher suggests two ways of eliminating the dangers from reactors. One is to choose a type that is inherently safe. The other is to place the reactor in the middle of an uninhabited desert.

There is a third course that involves two kinds of precautions. One can build into the reactor all kinds of safety controls to minimize the danger of an accident. Sir Christopher seems to be more skeptical than I am of the value of such measures. The other precaution is to design the reactor so that an explosion could take place without dousing the neighborhood with radioactive materials.

One way in which this is done is to enclose the reactor by a strong and gas-tight envelope of some sort. This is what we are doing at the reactor being built near Schenectady. We believe that there are many types of reactors where an explosion can be contained by a less elaborate and expensive structure than this one.

The several reactors we have built or are building at our laboratories or near university campuses are all of the inherently safe type. However, as I have suggested, we are not willing to limit our planning for future power reactors to such types, and we are constantly investigating how other [cheaper, more efficient] types can be made safe enough to put in populous areas.

In considering the question of safety and location of reactors, we do not depend entirely on our own technical staff. In 1947 a Reactor Safeguard Committee was established by the Commission, and in 1951 the Industrial Committee on Reactor Location Problems was established. These committees have recently been combined to form the Advisory Committee on Reactor Safeguards.

Obviously the Commission will not accept any plan for locating industrial power reactors until the public safety is assured beyond reasonable doubt. Needless to say, for certain suggested types of power reactors, extensive testing will be necessary.

cost of generation from nuclear energy is likely to fall, as usually happens when all newly born industries grow up, and the position therefore appears to be quite encouraging. In speaking of the cost of electricity produced from nuclear reactors, I have not included any credit for the value of the fissile material created in them. This fissile material can obviously be extracted and, subject to satisfactory development work, can be used as fuel in fast breeder reactors.

Three Stages to Power

We therefore visualize development in three stages. First of all, it should be possible to construct a series of thermal reactors that will both generate power and produce fissile material. This fissile material can be used as a fuel in fast reactors, giving us a second period in which thermal reactors and fast reactors run side by side to generate electric power. In the very long term and when the stock of fissile material is sufficiently great, it should be possible to discontinue the use of thermal reactors and to rely only on the fast reactors, which should breed at least enough new fissile material to make them self-supporting.

In the first or thermal-reactor period, we regard the reactor we are now building as only one of a number of alternative types from which power can be generated. I have already said that we hope that in a few years time we may be able after successful pilot operation to encourage industry to build thermal reactors of this type for large-scale power production. Meanwhile, it is intended that the Harwell research department shall proceed to examine alternative types of reactors, and select and do initial design development work on the next most promising type. When we have handed the gas-cooled reactor over to industry, we in the Production Division should then pick up the industrial design of this reactor and construct a first model of this alternative type of reactor, which we should in turn hand over to industry after satisfactory pilot operating experience.

You will see, therefore, that the British atomic energy organization is designed to work in the following steps: the Research Department at Harwell examines alternative designs and processes, selecting with such discussion as is necessary the best of these for development to the stage when it can be turned by the Production Division into an industrial project. When the Production Division has pioneered this industrial development and obtained satisfactory operating experience, further development will be turned over to industry.

Difficulties to be Faced

We should, I think, examine the major difficulties that lie in the way of the sort of development outlined. I suggest that the major difficulties are, first, supplies of uranium, second, the problem of disposing of fission products, and third, the problem of designing reactors that are inherently safe.

The problem of uranium supply can be and is being dealt with by patient geological search and prospecting and by the development of new chemical processes to make use of low-grade ores economically possible. I am sure that chemical and other processes can be discovered to deal with fission products more efficiently than at present. Chemical problems at least as difficult as this one have already been conquered in evolving present processes.

By far the most difficult and, to my mind, by far the most important of the three problems is the last; namely, that of evolving more advanced types of inherently safe reactors. I have already reminded you that any reactor that uses a coolant whose neutron absorption capacity outweighs its effect as a moderator has an inherent risk of an explosion, and this explosion can scatter fission products over a considerable area of ground. The magnitude of disaster in the event of such an accident is so great that no responsible engineer or industrialist could contemplate taking the responsibility for it. It is no use to complain that the scientists are laying down rules for safety distances that are unreasonable; they, in the light of the best information available, are doing nothing more than to state the intensity of radiation they think might exist at given distances from the accident.

Accidents almost invariably happen to all plants and machines that break into pioneering fields; many of the early bridges collapsed, many of the early boilers blew up, and many of the early airplanes (and indeed of the new type of airplanes produced today) crashed. Our trouble in the design of reactors lies primarily in the fact that engineers learn from their mistakes rather than from their successes, and in the case of a nuclear reactor the penalty for failure is so great that the responsible engineer dare not risk it.

It seems to me that it is absolutely essential that our knowledge of the safety of the reactors should be improved and that we should learn more about the effect of an accident. As things stand today, the only type of reactor you or we could contemplate building in a reasonably populated area is one where the coolant has a greater effect as a moderator than as a neutron absorber. This rules out all the reactors other than those that are gas-cooled, or heavy-water moderated and heavy-water cooled, or certain designs (using enriched uranium) with light water used both as a moderator and as a coolant. Most of the other types of thermal reactors involve hazards that would incline us to build them in remote districts. For a slightly different set of reasons, it is also necessary to build fast reactors remotely.

It is, to my mind, unsatisfactory to suggest that a reactor that is inherently unsafe can be made safe by the application of mechanical controls and gadgets; all of these can fail. It seems to me that true safety can be achieved only if it is inherent in the physical characteristics of the reactor core.

There is, however, one further point which should be borne in mind. The hazards are at present being assessed only on the basis of calculations. We have no practical experience of what happens if a reactor runs away. It seems well worth while to build a reactor in a remote district, purely with the intention of making it become super-critical to find out what actually happens under these conditions. Such a test would cost no more than the trial of a single atomic bomb, and it might give information of tremendous value. May I suggest that with all your tremendous resources of money and of technical capacity in America, and with the great areas of thinly populated country conveniently at your disposal, this is an experiment that you might well carry out and that might pay handsome dividends.

* * *

The speech on which this article is based and the comments by H. D. Smyth were both presented at the second annual conference on atomic energy in industry of the National Industrial Conference Board, New York, N. Y., October 30, 1953.

RADIOLOGICAL UNITS

Revisions were made in the recommendations of the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, Denmark, in July, 1953. The revised recommendations were released on January 1; the section on definitions and units is printed here with notations of changes from the 1951 section (NU, Jan'51, p. 28).

The major change is establishment of the "rad" as a unit (items 3, 4, 9). This conflicts with item 6 in the 1951 section on units, which stated that the ICRU did not recognize "special names or symbols for quantities which are merely multiples of the fundamental unit." Also, opinions expressed in items 3 and 8 of 1951 have been translated into action.

new definitions

1. **Intensity of radiation** is the energy flowing through unit area perpendicular to the beam per unit time. It is expressed in ergs per square centimeter per second or watts per square centimeter.

2. **Quantity of radiation** is the time integral of intensity. It is the total energy which has passed through unit area perpendicular to the beam and is expressed in ergs per square centimeter or watt-seconds per square centimeter.

new unit 1 rad = 100 ergs/gm

3. **Absorbed dose** of any ionizing radiation is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It shall be expressed in **rads.**

4. **The rad** is the unit of absorbed dose and is 100 ergs per gram.

same as 1950 ¶2

5. Inasmuch as calorimetric methods of determining absorbed dose are not usually practicable, ionization methods are generally employed. The quantity which must be measured is the ionization produced in a gas by the same flow of corpuscular radiation as exists in the material under consideration. The energy, E_m, imparted to unit mass of the material is then essentially related to the ionization per unit mass of gas, J_m, by the equation

$$E_m = WsJ_m$$

where W is the average energy expended by the ionizing particles per ion pair formed in the gas, and s is the ratio of the mass stopping power of the material to that of the gas.

1950 opinion translated to action — data to be published

6. Since the calculation of the absorbed dose from measurements of ionization requires a knowledge of the parameters W and s as well as variables characterizing the radiation and the irradiated material, it is recommended that tables of the best available data be prepared and held under continual review.*

* Preliminary reports on this subject were presented to the ICRU and it is hoped will be published in the near future.

same as 1950 ¶4 and ¶5

7. **The roentgen** (r) remains the unit of X- and γ-ray dose. Its definition remains unchanged:

> **The roentgen** shall be the quantity of X- or γ-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign. [Editor's note: Mass given is that of 1 cm^3 of dry atmospheric air at 0° C and 760 mm mercury.]

8. It becomes increasingly difficult to measure the dose in roentgens as the quantum energy of the X- or γ-radiation approaches very high values. The unit may, however, be used for most practical purposes for quantum energies up to 3 Mev.

new definition 1 gm-rad = 100 ergs

9. **Integral absorbed dose** is the integration of the energy absorbed throughout a given region of interest. The unit is the **gram-rad.** 1 gram-rad = 100 ergs.

same as 1950 ¶7, with note on Ra changed

10. Amounts of radioactive material shall be expressed in curies. The accepted definition of the curie is:

> **The curie** is a unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

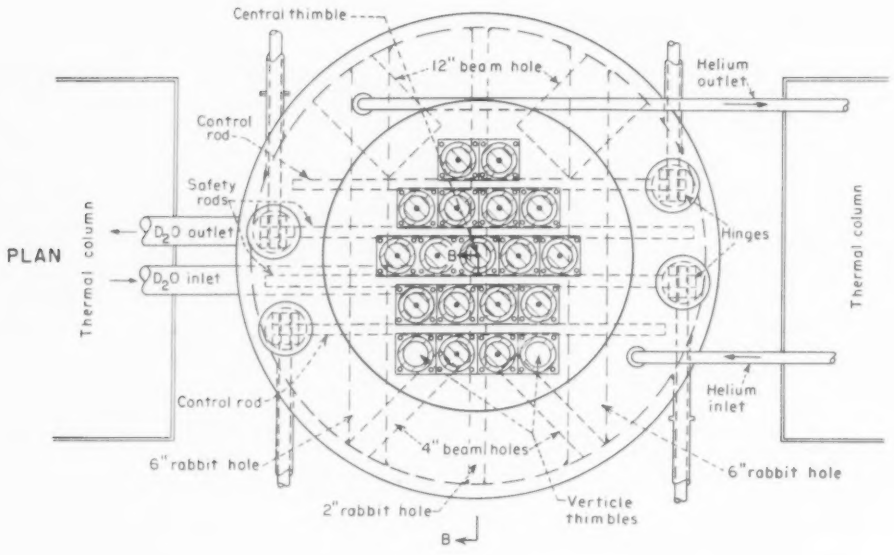
With this definition the curie is independent of the disintegration rate of radium.

action started on 1950 ¶8 — otherwise unchanged

11. It is suggested that the γ-ray emission be expressed in terms of roentgens per millicurie-hour at 1 cm from a point source. This quantity is different for every radioisotope. Preliminary data have been compiled relating to a number of radioisotopes and will be supplemented from time to time.*

same as 1950 ¶9

12. The ICRU requests the national standardizing laboratories to set up, interchange, and compare standards of X-rays, γ-rays and radioisotopes, maintain close contact with each other, and generally by every means within their power further the improvement of methods of standardization.



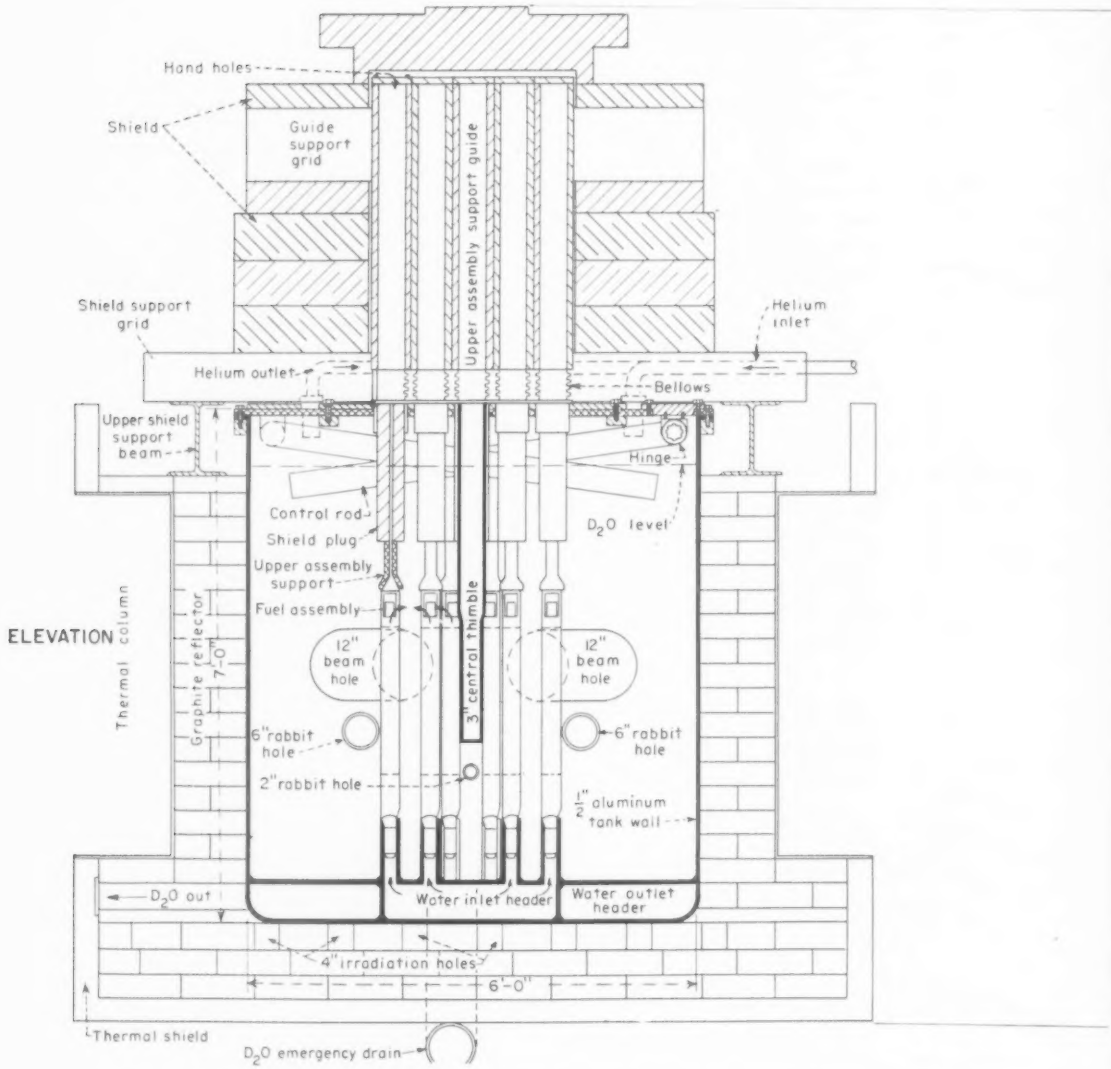
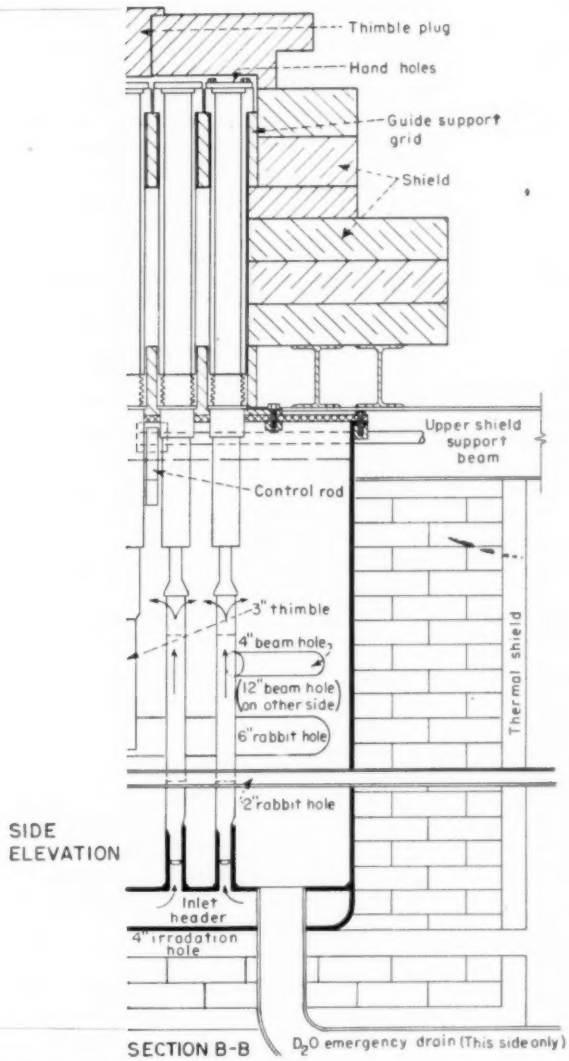


FIG. 1. Orthogonal projection of the new Argonne National Laboratory research reactor (CP-5)

Plans For the New Argonne Research Reactor, CP-5

A new research reactor nearing completion at Argonne National Laboratory uses enriched-uranium fuel and heavy water as coolant-moderator. The design has a large experimental volume, yields high flux at low power, and is safe because of its long neutron lifetime and strong photoneutron background

By S. UNTERMYER
*Argonne National Laboratory**
Lemont, Illinois



showing top-view and cutaways of core and tank

IT WAS EVIDENT when design work started in 1948 that the proximity of our reactor site to large population centers made it necessary that the CP-5 reactor be extremely safe under all conditions of operation. Thus, a low-power reactor with a long neutron-lifetime was preferred.

The power considered for this reactor never exceeded a few thousand kilowatts of heat. It is planned that the reactor will actually be operated at 1,000 kilowatts. Since operating costs increase with design power-level, there were the strongest incentives to produce the required neutron fluxes at the lowest possible power. Thus high neutron intensity with low reactor power was the primary requirement. Regions of the reactor were arranged to provide high resonance and fast neutron fluxes. The reactor will provide unusually high fluxes of thoroughly thermalized neutrons.

As it was desired to use the reactor for the most difficult and varied types of experiments, the very best experimental facilities were needed. Large beam holes are practical with this design. Also, strong collimated beams of thermal or resonance neutrons are available for neutron velocity-selectors or other beam-type experiments. Design features are shown in Figs. 1–3.

Provision was required for intense irradiations of short duration. This

* Operated for the Atomic Energy Commission by the University of Chicago.

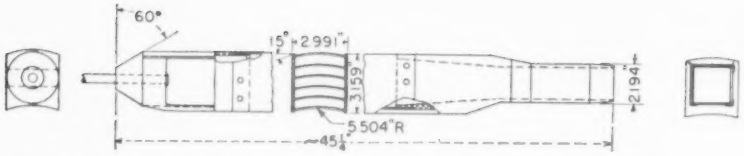


FIG. 2. Fuel element assembly. The initial loading will use 12-plate assemblies

required "rabbit" holes, penetrating between opposite faces of the reactor, so that samples can be driven through the high flux region near the reactor core and out into a counter within a very short time. However, location of the "rabbit" holes had to be compromised to the extent that expulsion of a strongly absorbing sample can not cause the pile to exceed prompt criticality.

Large through-hole facilities with fairly high fluxes were desired for engineering tests and for special types of physics work.

Low-flux biological irradiation facilities large enough for small mammals were also provided.

The requirements for this reactor were somewhat different than those for the Materials Testing Reactor, which is located in a remote area where operating power is not as severely limited. On the other hand, a more versatile and elaborate machine was required than is needed for training- or university-type reactors where low cost is often the primary consideration. Before the CP-5 design was chosen, several alternate types of research reactors were studied. It is interesting to note that a type of reactor different than any previously constructed was chosen to meet the special requirements.

Fuel, Coolant-Moderator Choice

Since thermal neutron flux is proportional to specific power, a research reactor should have the smallest possible critical mass. In this way, maximum flux will be obtained at any given power output. This is especially true for fluxes of 3×10^{13} or less, since at higher fluxes critical mass may be determined by poisoning and depletion rather than by clean critical size.

Among the various types of reactors studied, two systems had outstandingly low critical sizes. One was a light-water and U^{235} core of about 20 cm radius, surrounded by a beryllium reflector. Its structure was aluminum; calculations indicated that its critical mass would be about 1.5 kg. This reactor would have to be very small (volume less than 50 liters). The thermal flux would die out rapidly in the reflector, owing to the small core and relatively high absorption in beryllium. Manufacture of the reflector would have presented a problem because beryllium metal is hazardous to fabricate. Light-water piles are necessarily small, as the absorption of 70 liters of light water is about equal to that of 1 kg of U^{235}. This would have restricted the volume available for experimental facilities.

For these reasons, an enriched system consisting of a heavy-water moderator with a heavy-water reflector was adopted. Critical mass of this system was estimated to be about 850 gm. Allowing 150 gm for depletion and 100 gm for poison and experiments, total critical mass comes to 1,100 gm. Obviously, this arrangement had a cost disadvantage due to the initial investment of about 8 tons of heavy water. However, as heavy water does not absorb many neutrons, the only restriction on the size of experimental space in this reactor was the investment in heavy water to provide a reasonably thick reflector. A minor objection to the use of heavy water was the difficulty in handling core components without contaminating the moderator. Nevertheless, the major advantages of lower critical size and larger experimental volume led to the choice of a heavy-water U^{235} reactor.

Neutron Flux

Flux distributions are shown in Figure 4. Thermal flux is relatively flat with a slight bump in the reflector just outside the core. Table 1 shows the fluxes available in several reactors and estimates of the fluxes in the CP-5.

An interesting feature of the CP-5 is the unusual degree of thermalization of neutrons at the tank wall. Heavy water degrades fast neutrons in a mean distance of 11.7 cm. In this distance, absorption of thermal neutrons by heavy water is negligible. Consequently, of the neutrons entering the graphite outer reflector, only about 1 in 150 will be above thermal energy. This is a cadmium ratio of about 600 for a $1/V$ absorber. The thermal flux at this point is about 5×10^{12}.

General Arrangement

The heavy water is contained in a 200 cm diameter right-cylindrical tank, mounted vertically (Fig 1). The tank is pierced by horizontal beam holes. Vertical thimbles extend through the tank cover.

Each fuel element is an assembly

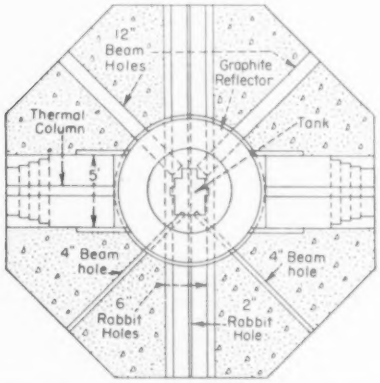


FIG. 3. Schematic showing core and experimental facilities

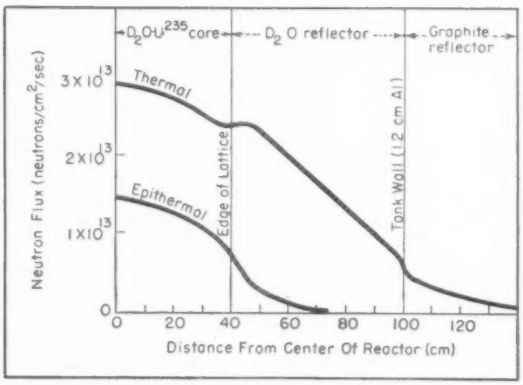


FIG. 4. Neutron flux distribution in CP-5 reactor at 1,000 kw

3 × 3 inches square and about 30 in long (Fig. 2). The active section is made from 10 aluminum "sandwiches" 3 in × 24 in × 0.060 in thick. Each sandwich consists of a sheet of aluminum-uranium alloy fabricated between two 28-aluminum sheets into a solid plate. It is sufficiently tight to prevent escape of fission products. The plates are clad with a thin layer of 728-aluminum, which corrodes preferentially. A conical end-box is welded to the bottom of each assembly. The end-box of each element fits into a grid at the bottom of the core. Each fuel assembly contains about 75 gm of U^{235}.

Sixteen of these assemblies are grouped in the central part of the tank to form a lattice. The approximate volume of this lattice is 300 liters, which is equal to the volume of a sphere of about 40 cm radius.

Because of depletion, assemblies will be replaced twice a year. This must be accomplished without contaminating the heavy water with light water from the atmosphere. Assemblies will be withdrawn through $4\frac{1}{2}$-in tubes extending upward through the shield from the tank top. A half-inch lifting rod is attached to the top of each assembly. A metallic shield fitting around each rod serves to align the top of each fuel assembly.

Cooling and Heat Transfer

Heavy water enters the tank by flowing up through the fuel assemblies. It then mixes with heavy water in the tank, and exits downward.

The flow-area per assembly is 49 cm^2 and the heat generation in the hottest assembly is about 100 kw. For a coolant velocity of 1 meter/sec, the temperature rise of the cooling water will be only 5° C.

The film coefficient of heat transfer for a heavy-water velocity of 100 cm/sec is about 0.15 cal/cm^2/sec/°C. As the maximum heat flux is about 4.5 cal/cm^2 sec, the film temperature differential will be 30° C.

To maintain the required velocity of 1 meter/sec in the center assemblies, coolant circulation at about 1,200 gallons per minute will be required.

Pile Control

It is planned to use hinged control rods similar to those in the CP-3. Design of the mechanism has been rearranged so that bearings and rods can be replaced by remote control. Additional vertical rods will also be used.

Because many of the neutrons have a long life expectancy in the reflector, the pile will have a sluggish characteristic. This may be advantageous from the standpoint of reactor hazards and safety.

Reflector Cooling

In CP-3, the temperature rise in the graphite is about 10° C. This heat is principally due to gammas that liberate about 750 watts of heat in the reflector.

In the CP-5, these gammas amount to 4 kilowatts. In addition, capture gammas from absorption of thermal neutrons may produce about 10 kilowatts. Thus, since the graphite temperature rise will be about 200° C, water-cooling coils will extend through the graphite.

Experimental Facilities

In addition to the major experimental facilities described in Table 2, several large vertical thimbles can be added to the reflector. Other beam holes extending to the tank wall can also be added easily. END

No Significant Changes

This article was developed from the original proposal for CP-5, issued in November, 1948. Thus, this description does not reflect the detailed engineering changes made since that time; however, there are no basic discrepancies. Many of the minor alterations made as the design progressed are too small to be shown on the figures. For instance, the details of fabrication of the top shield has been changed, and a "Boral" sheet is used inside the thermal shield. Some of the reactor dimensions have been altered fractions of inches, and some small, auxiliary, vertical control rods have been added, buried in the upper shield.

TABLE 1—Neutron Fluxes in Various Research Reactors

Reactor	*Fluxes (neutrons/cm²/sec) Thermal*	*Epithermal*	*Virgin*
CP-5 Research			
Core	3×10^{13}	1×10^{13}	1×10^{12}
Edge of tank	5×10^{12}	2×10^{10}	1×10^{7}
Chalk River—NRX (30 Mw)	5×10^{13}	6×10^{13}	2×10^{12}
CP-3 (enriched)			
Core	3×10^{12}	6×10^{11}	3×10^{11}
Edge of tank	7×10^{11}	1×10^{11}	2×10^{10}
CP-4 (EBR)	1×10^{12}*	2×10^{14}†	1×10^{11}

* In graphite. † Fast.

TABLE 2—List of Experimental Facilities in the CP-5 Reactor

Quantity	*Facility*	*Fluxes (neutrons/cm²/sec) Thermal*	*Epithermal*
1	3-in central thimble	3×10^{13}	1×10^{13}
7	3-in auxiliary thimbles	2×10^{13}	1×10^{13}
2	12-in beam holes	2×10^{13}	3×10^{12}
2	4-in beam holes	2×10^{13}	1×10^{13}
2	6-in thru beam holes	2×10^{13}	1×10^{13}
1	2-in rabbit	2×10^{13}	1×10^{13}
2	8 × 12-in biological holes	2×10^{12}	1×10^{10}
4	4-in beam holes	2×10^{13}	1×10^{12}
2	5-ft thermal columns	5×10^{12}	2×10^{10}

Radioactive Tracers for Tagging Special Steel Melts

To trace steel melts of critical composition, such as for reactor construction, radioisotopes offer several advantages over customary chemical analysis: time involved negligible, little plant space necessary, melt identification definite

By DAVID L. DOUGLAS

Chemistry and Chemical Engineering Section, Knolls Atomic Power Laboratory Schenectady, New York*

THE SECRET OF SUCCESS in many industrial fields lies in the use of special steels or other alloys. With alloy steels, some particular property, such as corrosion resistance or high-temperature strength, can be essential to the successful operation of the device under consideration. Nowhere is this more true than in the field of reactor technology.

The usual method of operation is to order the alloy steel as a special melt and then, by way of insuring that no substitutions are made, to set up an extensive inspection and analysis program to follow the steel from the mill to finished article. Clearly this is both expensive and uncertain, the latter since one cannot commit all the steel to analysis and still have a finished product. As an answer to this problem, inclusion of a radioactive tracer in the original steel melt would appear to be ideal; not only would the laboratory space committed be negligible, but a 5-min check would suffice where a chemical analysis involves 15 man-hr.

* Operated by the General Electric Co. for the Atomic Energy Commission.

It is axiomatic that the amount of activity added must be kept as small as is consistent with the required detection sensitivity. Because several tons of the steel are likely to be accumulated in a warehouse or in the final product assembly, the maximum permissible specific activity, in consideration of the personnel hazard, is of the order of millicuries per ton.

Discussion

The important limits that constrain the selection of the nature and amount of the radioactive tracer employed are discussed next.

Detector sensitivity. To obtain satisfactory levels of sensitivity with readily available detection equipment, the emitted radiations must be gamma rays of energy greater than about 0.3 Mev or beta particles of energy greater than about 0.5 Mev. Thus low-energy beta-emitting and electron-capturing nuclides are eliminated. The discussion of detection sensitivity must refer to the specific problem in terms of the smallest fabricated part whose activity is to be measured. In this article, this will be taken as 1 gm.

The efficiency of radiation detection is related directly to geometry and range of the radiation, i.e., to the amount of material that the detector can "see." Since destruction of the sample by dissolution is prohibited, gamma emitters are much to be preferred over beta emitters on account of the limited range of beta particles in dense solids such as steel. Scintillation counters are the preferable detectors because of their high efficiencies for gamma rays.

Radioisotope availability. The radioisotope should be easy to obtain, e.g., sold by the AEC.

Metallurgy. Chemical and physical properties of the steel must not be altered by the tracer. (In reactor applications, nuclear properties must be considered too.)

One method of tagging is that the tracer be an isotope of one of the constituents of the alloy. Another is that the actual amount of material added be so small, 0.001% or less, that the properties of the alloy are not altered. The added material must mix thoroughly in the melt and have no tendency to collect in a slag or on the walls of the crucible.

Time. A lower limit of a few months on the half-life of the activity is set by the fact that it will usually be necessary to "follow" the steel for about a year. Shorter half-lives would mean inordinately high activity levels at the beginning of the period. The upper limit may be important if the purchaser is required by the steel mill to be re-

sponsible for (i.e., to purchase) the mill scrap. In any event, prudence requires as short a half-life as possible. One year would seem to be a reasonable upper limit.

All of these requirements are met very satisfactorily by the nuclide tantalum-182. Its nuclear characteristics (*1, 2*) are 110-day half-life, 0.53-Mev betas, and 1.1-, 1.2-Mev and other gammas. One of the outstanding advantages of tantalum-182 is that it is readily available in very high specific activities—up to 50 curies/gm. This means that entirely insignificant amounts of the element would have to be added.

Experimental

Simple experiments have been carried out to determine the lowest specific activity required for easy "tracing" of a steel and the dose rate to be expected in the neighborhood of a large accumulation of the tagged metal.

Tracer preparation. Two pieces (60.6 and 111 mg, respectively) of 25-mil tantalum wire were irradiated in the reactor at Brookhaven National Laboratory for an equivalent *nvt* of 9×10^{14} flux-seconds. The tantalum content was determined spectrographically and found to be more than 98%. Qualitative analysis showed no impurities in quantity sufficient to produce appreciable radioactivity on irradiation.

A few milligrams from each specimen were dissolved in hydrofluoric acid and the absolute beta activity determined by counting an aliquot of each of the diluted solutions. Since the decay scheme of Ta^{182} is not known (*1, 2*), it was decided to use absolute beta counting for standardization rather than the less reliable gamma counting techniques. The aliquots were evaporated to dryness on gold-coated Pliofilm* mounts (less than 0.7 mg/cm²), and the activity determined with 4π counters (*3*) of two different designs—both of which have been successfully used for several months at KAPL and checked against standard activities supplied by the National Bureau of Standards. The activation results are given in Table 1.

With identical aliquots of these same solutions, the counting efficiency of the scintillation counter for Ta^{182} was determined. This counter is a standard instrument in which the detector is a NaI(Tl) crystal $\frac{1}{4}$ in. thick and 2 in. in diameter. The background with lead shielding averages about 55 cpm. Accordingly, the Ta^{182} counting efficiency under the experimental conditions is $6.5 \pm 0.1\%$.

Preparation and sampling of billets. As stated previously, two cylindrical billets of mild steel were vacuum cast in graphite molds by induction heating. Dimensions of the as-cast billets were 6.1-cm diameter, and 19.5-cm length. The tantalum wires were added before melting. Expected (calculated) specific activities are given in Table 2.

To be certain that the activity was uniformly distributed throughout the metal, chips were collected by machining about 10 mils off the radius of each billet, and by drilling three $\frac{1}{4}$-in.-diameter holes equally spaced along the axis of each billet. A 1-gm sample of each lot of chips was mounted on cardboard and counted with the scintillation counter. From the average of these determinations, the "observed specific activities" were obtained and are tabulated in Table 1.

In view of the considerable differences between the chip mounts and the standard mount used to determine the counter efficiency, the agreement between the calculated and observed specific activities is considered satisfactory. Further, the agreement between chip samples from any one billet showed that the activity was distributed uniformly to within 3% or better.

The original billets were "counted" with a standard scintillation probe* and with a beta-gamma survey meter;† results are shown in Table 2. Also shown are the survey-meter counting rates observed with pieces of the billets weighing approximately 1 lb. Measurements were made with the detectors all but touching the sample.

Since an estimation of the radiation dose rate requires a knowledge of the activity as a function of thickness of tagged metal, a series of disks of varying thickness were cut from each of the billets. These disks were then counted in the scintillation counter, care being taken to maintain a fixed distance between the top of the disk and the bottom of crystal can.

The data for disks from billet No. 2 are presented in Table 3. The "efficiencies" are the usual ratio of observed counts to total activity in the sample. The "relative counting efficiencies" are ratios of the observed counting rates to those expected if the sample were counted with the efficiency of the 50-mil disk. These efficiencies are then a measure of the self-absorption of the radiation by the metal.

The efficiencies are presented in graphical form in the illustration on page 18. The value for the 2.00-in. disk was obtained by extrapolation. Clearly this measurement is approximate in that it takes no account of scattering by the walls of the counter

* Rubber hydrochloride, sold by Reed Laboratories, Akron, Ohio.

* An example is the RCL scintillation head, mark 10, model 10, Radiation Counter Laboratories, Chicago, Ill.

† For example, alpha-beta-gamma survey meter, model SU-5, Tracerlab, Inc., Boston, Mass.

TABLE 1—Specific Activity Data*

Billet	Weight of Ta wire (mg)	Total activity (curies)	Specific activity (curies/gm) Calculated	Observed
No. 1	55.3	5.21×10^{-6}	1.15×10^{-9}	$1.28 \pm 0.03 \times 10^{-9}$
No. 2	95.1	9.06×10^{-6}	2.00×10^{-9}	$2.44 \pm 0.07 \times 10^{-9}$

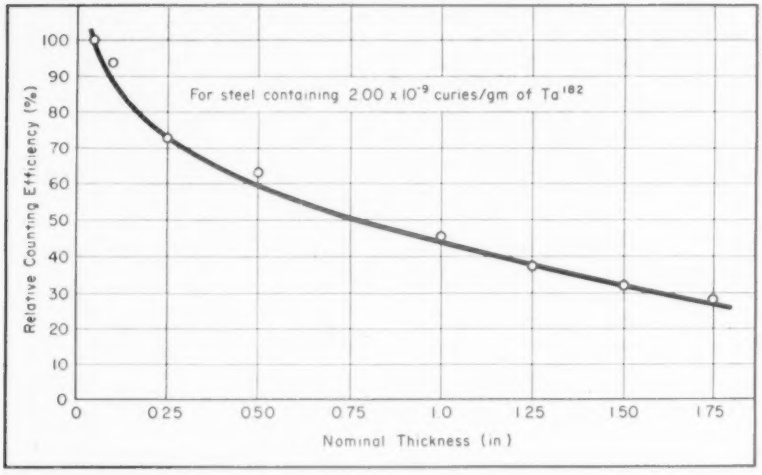
* All activities corrected for decay.

TABLE 2—Results of Survey of "Tagged" Billets

Place counted and physical arrangement	Scintillation probe (cpm)	Beta-gamma survey meter (cpm)
Background	3,550	~200
Billet 1—end on	6,150	
Billet 1—side	7,030	1,700
Billet 2—end on	12,100	
Billet 2—side	13,700	3,900
529 gm of billet 1	—	800
567 gm of billet 2	—	1,500

TABLE 3—Counting Efficiencies vs Thickness for Billet No. 2

Nominal thickness (in.)	*Weight (gm)*	*Surface density (gm/cm²)*	*Total activity (curies)*	*Gamma counting rate (cpm)*	*Efficiency (%)*	*Relative counting efficiency (%)*
0.050	30.7	1.14	0.614×10^{-7}	12,275	9.0	100
0.100	59.7	2.03	1.19×10^{-7}	20,544	7.75	94
0.250	153.1	5.21	3.03×10^{-7}	44,712	6.65	73
0.500	311	10.6	6.22×10^{-7}	71,732	5.2	63
1.00	567	19.3	11.34×10^{-7}	92,778	3.7	45
1.25	720	24.5	14.4×10^{-7}	98,665	3.1	37
1.5	878	29.9	17.56×10^{-7}	102,962	2.6	32
1.75	1,031	35.1	20.62×10^{-7}	107,575	2.35	28
2.00	1,184	40.3	23.65×10^{-7}			23 (est)



RELATIVE counting efficiency vs thickness

shield and other effects; however, it is more than sufficiently accurate for the purpose at hand.

Dose-rate factor. The preceding activity measurements have all involved counting rates determined with a scintillation counter and are not readily converted into dose rates. To obtain a factor for converting activity in curies into dose rate, the following simple experiment was carried out:

The dose rate was measured at various distances from a nominal 1-mc Ta^{182} source obtained from Oak Ridge National Laboratory. A 4π count of an aliquot of the solution established the total absolute beta activity of the source as 0.76 mc. The instrument used in the dose-rate measurement was a recently calibrated "Cutie Pie" gamma survey instrument.*

The results for the range of interest were: 0.2 mr/hr at 2.0 meters; 0.4 mr/hr at 1.5 meters; 0.9 mr/hr at 1.0 meters, and 3.8 mr/hr at 0.5 meters. Note that the inverse square law is obeyed to a first approximation.

Conclusions

The experiments show that steels containing amounts of Ta^{182} of the order of 1×10^{-9} curies/gm (1 mc/metric ton) can be readily identified with counting equipment commonly available in radiochemical laboratories. For large pieces—1 lb and greater—a beta-gamma survey meter is sufficient. Smaller parts require the use of a scintillation counter.

What remains is to calculate the minimum specific activity that meets our detection condition, viz., ability to detect the activity in 1 gm of metal after 1 yr, and, using this, to estimate the maximum probable dose rates.

* For example, radiation survey meter, model SU-1E, Tracerlab, Boston, Mass.

With a sample-to-background activity ratio of unity and a background of 50 cpm, the required final specific activity is 0.31×10^{-9} curies/gm. Thus the initial specific activity is 2.5×10^{-9} curies/gm or 2.5 mc/ton.

In estimating the radiation dose rate in the neighborhood of a large accumulation of such steel, we assume the particularly severe case of a hollow sphere 1-in. thick and 1 meter in radius. The total mass of such a sphere would be about 2.5×10^6 gm, the total activity about 6.3 mc. At the center of the sphere, the dose rate would be $6.3 \times (0.9/0.76) \times 0.45 = 3.4$ mr/hr, where the second factor is the dose-rate and the third is the relative efficiency for metal 1-in. thick. This dose rate is only about half that deemed safe for day in and day out exposure (*4*). An inspection of the relative efficiencies in Table 3 shows that significantly higher dose rates would not be obtained by increasing the thickness of the sphere. Since an inverse-square law relates dose rate to distance from the source, decreasing the sphere radius, while maintaining the same mass, does not increase dose rate.

The conclusion is that it is entirely safe, insofar as personnel are concerned, to employ radioactive tracers in amounts of the order of 1 mc/ton for tagging special melts of ferrous or other alloys. However, it should be realized that this activity is 220 times the maximum activity of contaminated scrap steel (10 dpm/gm) released by the AEC and considered as technically nonhazardous to sensitive industries.

* * *

The assistance of the following individuals and departments of the Knolls Atomic Power Laboratory is gratefully acknowledged: Mr. F. D. Nicol and other members of the Manufacturing Unit for many helpful discussions pointing up the importance of the problem; Dr. D. W. White and Mr. R. V. Gray of the Metallurgy Section for preparing the steel billets; Special Material Shop for machining the billets; and Mrs. A. C. Mewherter of the Chemistry Section for assistance in carrying out the radiochemical work.

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Simplified Autoradiography Exposure Calculation

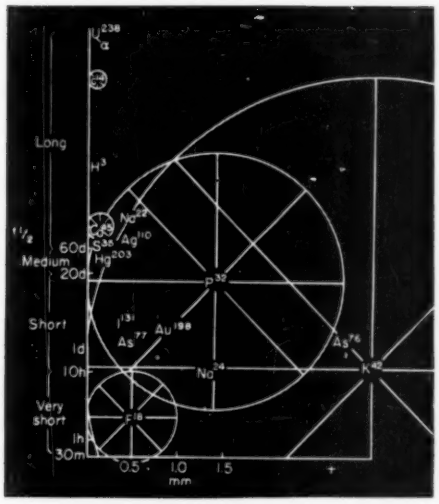

FIG. 1. Comparative half-lives and relative spread in emulsion from point source

Autoradiographic detail is improved by the use of weak beta emitters. To aid isotope selection, charts are used to compare half-lives and emission energies and to calculate exposure time from specimen activity

By WILLIAM W. WAINWRIGHT,* ERNEST C. ANDERSON, PRESTON C. HAMMER, and CHARLES A. LEHMAN
Radiobiology Section and Theoretical Division
Los Alamos Scientific Laboratory of the University of California
Los Alamos, New Mexico

RISING INTEREST in the application of autoradiographic techniques suggests clarification of the relative usefulness of radioisotopes when several are available for an experiment.

Before the advent of mica-window counters suitable for the measurement of weak beta emissions, there was a necessary preference among investigators for isotopes with a strong beta emission. This impression persists, and H. M. Leicester suggests that: "The most suitable substance for studies of this nature (permeability) in teeth is . . . P^{32}. This is readily obtainable and its comparatively long half-life of 14.3 days permits its use in long-term experiments" (*1*).

* PRESENT ADDRESS: College of Dentistry, University of Illinois, Chicago, Illinois.

Sharpness of image. Comparison of P^{32} with Ca^{45}, from the standpoint of relative sharpness of autoradiographic image, gives a strong preference to Ca^{45} since it emits a much weaker beta particle.

This relationship is illustrated in Fig. 1. The radius of the small circle around Ca^{45} is a measure of its relative unsharpness or spread in an autoradiographic emulsion from a point source. By comparison, the emission from P^{32} spreads out in an enormous circle. The spread plotted is derived from the average energy of the beta particles emitted and their range in autoradiographic emulsion (*2*). The spread is not plotted in exact dimensions.

A number of isotopic emissions are plotted in Fig. 1 in relative positions. From the standpoint of sharpness of the autoradiographic image, alpha emitters are of course preferable in the few cases where they are available because of their shortness of range in autoradiographic emulsions.

Comparison of half-lives. The "comparatively long half-life" of P^{32}, 14.3 days, permits only certain types of short experiments. If the tissue or other specimen has a low uptake of P^{32}, the autoradiographic exposure may be inadequate. The rule of thumb for relative autoradiographic exposure states that half of the remaining total exposure is attained in 1 half-life (*3*), and that the maximum useful exposure is realized in 3 to 5 half-lives. Thus, if the uptake of P^{32} is insufficient to give an adequate exposure in 6 to

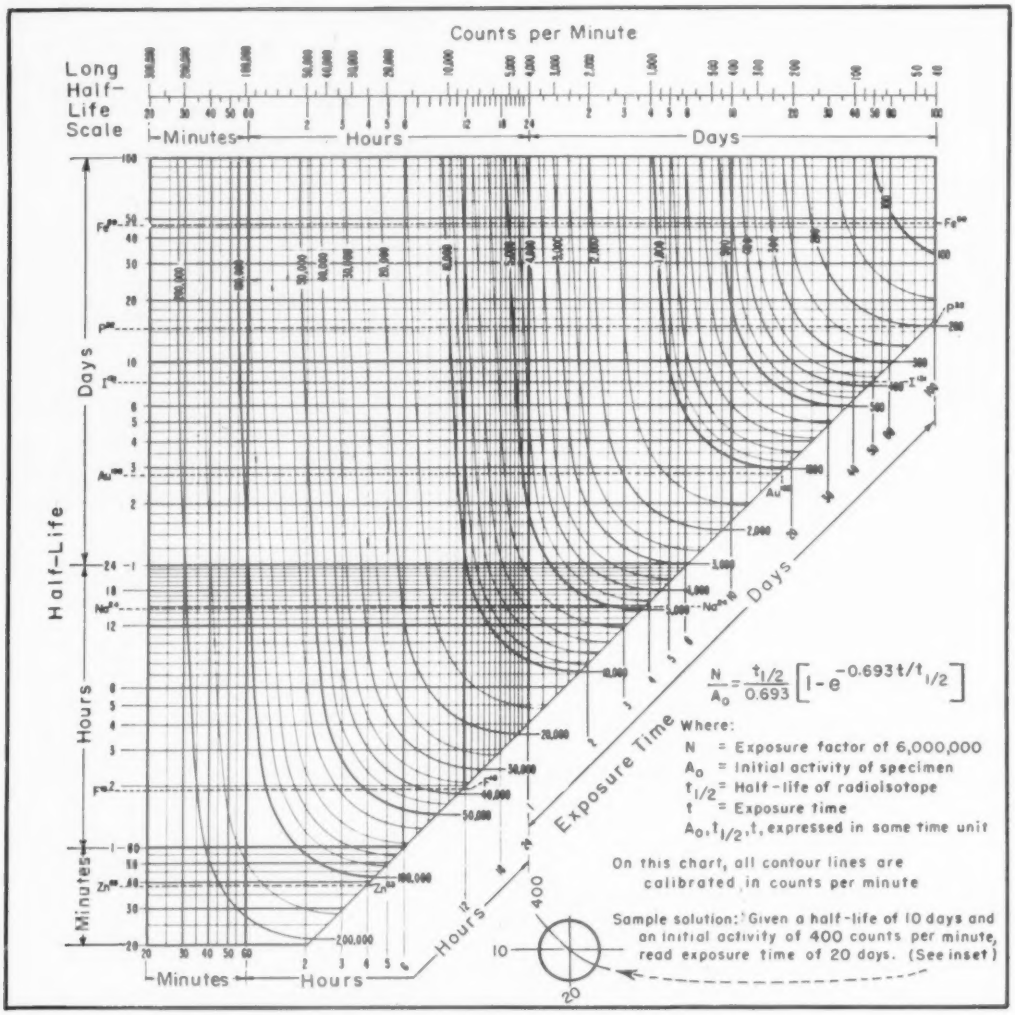
Counts per Minute
Long Half-Life Scale
Minutes
Hours
Days
Half-Life
Days
Hours
Minutes
Exposure Time
$\frac{N}{A_0} = \frac{t_{1/2}}{0.693}\left[1 - e^{-0.693\,t/t_{1/2}}\right]$
Where:
N = Exposure factor of 6,000,000
A_0 = Initial activity of specimen
$t_{1/2}$ = Half-life of radioisotope
t = Exposure time
$A_0, t_{1/2}, t$, expressed in same time unit
On this chart, all contour lines are calibrated in counts per minute
Sample solution: Given a half-life of 10 days and an initial activity of 400 counts per minute, read exposure time of 20 days. (See inset)

FIG. 2. Network chart for calculation of autoradiographic exposure time for beta emitters

10 weeks, the autoradiographic aspect is lost or the experiment must be repeated with an increased dose.

Phosphorus-32 is compared with Ca^{45} in this way in Fig. 1. P^{32} is rated as having a relatively *short* half-life, while Ca^{45} is rated as *long* (180 days). The difference between a maximum exposure of 6 to 10 weeks and $1\frac{1}{2}$ to $2\frac{1}{2}$ yr is very great indeed. The advantage in the use of Ca^{45} lies not so much in the increased exposure time available, since emulsions fog after periods of several months, but primarily in the longer time available for the experiment. Since exposures of more than several months are undesirable, half-lives greater than 60 days are considered infinite from the autoradiographic standpoint. If a choice is open, a radioisotope is more desirable for autoradiographic purposes if it has a weak emission (close to the left side of Fig. 1) and has a long half-life (upper part of Fig. 1).

Specimen activity. The exposure of autoradiographs is often mentioned as being a function of the activity of the specimen. In fact, the formula of Axelrod and Hamilton (*4*) has proved very useful. They state that 2-million to 10-million beta particles striking the emulsion per square centimeter give a suitable exposure.

In practice, the radioisotope usually concentrates in structures to form lines or limited areas of density. This tendency, plus the latitude of autoradiographic emulsions, makes it possible to predict roughly the exposure time with the formula of Axelrod and Hamilton. This assumes that it is the beta emissions of a radioisotope, rather than its gamma emissions, that produce the principle autoradiographic exposure.

Although experimental data is not available for emissions of the range of energy produced by radioisotopes, the reason for the success of the formula of Axelrod and Hamilton may well lie in a correspondence between the relative sensitivity to beta and gamma emissions on the part of the Geiger tube and autoradiographic emulsions. In the case of the Geiger tube, there is only approximately a 1% efficiency to gamma emissions.

Exposure-Calculation Chart

Due to the complexity of the decay formula, it is difficult to apply the formula of Axelrod and Hamilton to isotopes of short half-life. For this

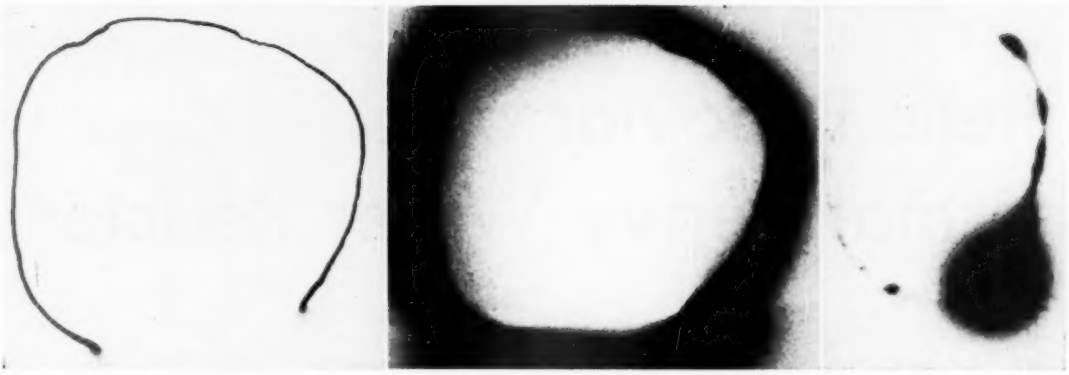

FIG. 3. Autoradiographs of alpha emitter showing, from left, proper exposure and overexposure. At right, grossly irregular isotope distribution for which use of network chart would give underexposure of most areas

purpose, a network chart for exposure calculation for beta emitters is presented in Fig. 2. A specimen of approximately 1 cm^2 is assumed.

Short-lived isotopes. To use the chart for short-lived isotopes, find the intersection of half-life and specimen activity (in counts per minute) and read exposure time at the bottom. The result is accurate only in terms of the formula.

In practice, a simple correction will usually be applied to the activity of the specimen to correct for individual conditions, e.g., counter efficiency, isotope emission, isotope localization, specimen area, emulsion sensitivity, desired autoradiographic density, and processing procedure. For example, it may be found from experience that the chart is made useful if the specimen activity is corrected to twice (or other factor) that indicated for a given exposure time.

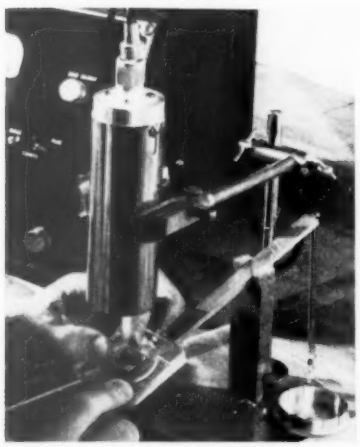

FIG. 4. Apparatus for rapid measurement of specimen activity

Determination of activity needed. One major practical use of the chart is the prediction of minimum activity needed for adequate exposure. For example, if an experiment is planned with Na^{24}, the chart predicts that exposure will be inadequate if the activity of the specimen is below 5,000 cpm. The triangular area at the lower right represents inadequate activity in the specimen.

The regions in Fig. 2 above the curved portions of the lines for specimen activity are areas in which the half-life is greater than twice the exposure time. In these regions the error introduced by considering the half-life as infinite is slight from the autoradiographic standpoint. The greatest use of the chart, therefore, is in the long half-life scale across the top. For example, on this scale an activity of 4,000 cpm calls for an exposure of 24 hr. This would apply to all radioisotopes with half-lives greater than two days; however, if the exposure is equal to the half-life, the exposure time found by using the "infinite" half-life scale is about one-half of that required. When it is desired to change the scale to a particular relation indicated by experience, this may be done by tracing the appropriate horizontal scale from Fig. 2 and multiplying the values for specimen activity by the appropriate factor. Likewise, scales can be prepared for a particular short-lived isotope by tracing the horizontal line corresponding to its half-life. The exposure times for each activity are found as indicated in the small circle at the lower portion of Fig 2.

The necessity for proper autoradiographic exposure can be demonstrated even with emissions of such short range as alpha particles. Although their range in emulsions is in the order of only 20μ, Fig. 3 shows that gross misinterpretations are not impossible.

In practice, the chart for exposure calculation is useful even in different laboratories and for different personnel.

Autoradiographic apparatus. A rapid uniform technique for measuring the beta activity of specimens for autoradiographic purposes can be achieved by such an apparatus as that shown in Fig. 4. The specimen is set in soft wax and pressed flush with the edge of the pan with a flat object. A slot is cut to hold microscope slides in constant position. The lever is adjusted so that the upper edge of the pan comes flush with the Geiger-tube guard.

The great usefulness and simplicity of survey autoradiographs (*5*), the advent of beta nuclear track autoradiographs (*6*), the perfection of methods for autoradiography with water soluble radio-active compounds (*7*), and the increasing availability of labeled compounds promises great expansion of autoradiographic applications.

* * *

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Kinetic Behavior of a Thermal Heavy-Water Reactor

A fast-detection technique was used to study power-level variations following a sudden change in reactivity of the JEEP reactor. Comparison with theory yields a value for the average neutron lifetime in the reactor of 2×10^{-3} sec

By A. LUNDBY and N. HOLT
Joint Establishment for Nuclear Energy Research
Kjeller, Norway

REACTOR CONTROL DATA and important reactor constants can be derived by studying the kinetic behavior of a reactor. This article deals with an experimental study that makes use of theory (*1*) to evaluate the power-level transients observed following changes in reactivity.

Experimental Approach

The usual experimental technique involves producing either a periodic or step-function local change in the multiplication factor. The amplitude and phase relationships or the detailed variations in neutron flux that result are measured.

When the reactivity is suddenly changed from zero to a positive (or negative) value, the neutron flux responds with an initial steep rise (or fall) with a time constant amounting to a few-tenths of a second. This is followed by a slower rise (or fall). To record the initial fast variation in neutron flux, it is necessary to change the reactivity within 10^{-1} sec and to follow the consequent changes in flux during time intervals of the same order of magnitude.

This article deals with the situation that arises when the excess effective multiplication factor is suddenly made positive. The change was accomplished by projecting a piece of neutron-absorbing cadmium out of the effective reactor volume during an interval of not more than 6×10^{-2} sec. This caused a rapid increase in reactivity from zero (or a small negative value) to a positive value of the order of 10^{-3}.

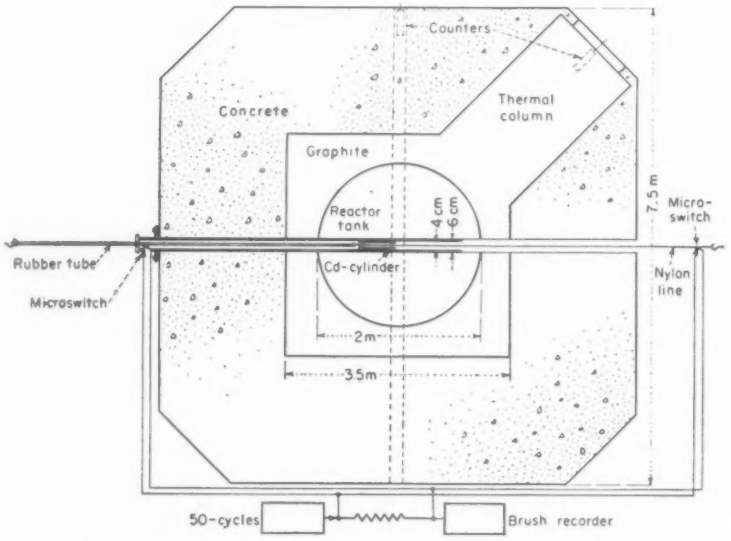

FIG. 1. Schematic diagram of experimental arrangement. Dimensions are not to scale

Equipment

The absorber consisted of a 1-mm thick and 10–15-cm long cadmium cylinder placed in a Lucite container to form a "rabbit." The Lucite-surfaced rabbit moved smoothly inside an aluminum tube in an isotope channel of the reactor (Fig. 1). A Nylon line was used to pull the rabbit into the reactor. When the rabbit was inside the reactor core, the rubber tube was stretched to about twice its normal length. The release was effected by cutting the Nylon line. The rabbit then snapped to a stopper at the outer surface of the concrete shield.

To obtain a record of the variations in reactor power level, a scintillation detector was located in either an isotope channel or the thermal column. The scintillation cell consisted of a 4-cm-diameter and 2-cm-deep Lucite container filled with a solution of *p*-terphenyl in phenylcyclohexane (3 gm/liter). It looked at a 1-mm-thick Cd radiator, which served as a converter of neutrons into γ-radiation.

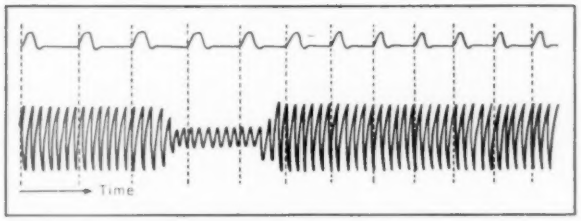

FIG. 2. Typical recorder pattern. Arrival of every 10^4th pulse is recorded on upper trace. Lower trace fixes time scale (50 cycles/sec). Amplitude of lower trace is reduced during transit time of rabbit

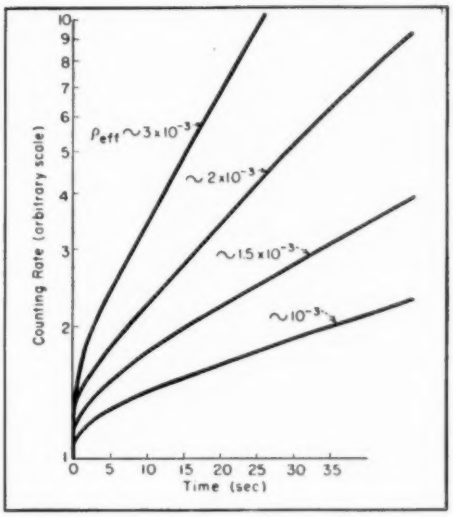

FIG. 3. Variation of neutron counting rate with time after ejection of rabbit. Curves based on 10^4, 5×10^4, or higher counts. Initial steep increase occupies longer time when shorter period follows. When initial power level is 500 watts or less, amplitude of initial fast rise is influenced by photoneutron background (2)

Light pulses from the γ-rays scattered in the scintillator were detected by an RCA 5819 photomultiplier. The output pulses were amplified in a cathode follower and a distributed amplifier and were then counted with a scale of 10^4. Over-all resolving time was 10^{-7} sec. Counting rate was proportional to reactor power level as long as the counting losses were negligible.

The output from the last stage in the scaler was applied to one channel of a Brush recorder. At each 8,000th pulse, the recorder received a current pulse that lasted until the 10,000th pulse arrived. The recorder chart traveled 10.5 cm/sec. Thus, a recorder pattern was obtained as shown in Fig. 2.

A 50-cycles/sec signal was applied to the other channel of the recorder. The amplitude of this signal was reduced to half its normal size during the traveling time of the rabbit. This was done by introducing a dropping resistor in series with this channel of the recorder by means of two microswitches, one at the release end of the rabbit track and one at the receiver end. The time during which the rabbit had an effect on the reactivity was one-quarter of this time of flight.

Measurements

The experiments were performed in the following sequence: The rabbit was pulled into the reactor and the power level stabilized to a value (0.1–1 kw) such that the counting rate in the scintillation counter was between 10^4 and 5×10^4 cps. The reactor was run at this power level for several minutes. The recorder was started, and a few seconds later the rabbit was released. The divergence was followed for several minutes.

The distance between consecutive peaks representing the arrival of 10^4 pulses was measured on the recorder chart. The 50-cycles/sec signal was used to translate the measurements into time. By inverting, counts per second were obtained.

In cases of very high counting rates, a correction had to be applied for counting losses. The correction was found by varying the power level of the reactor and recording the neutron flux with a BF_3-counter and the scintillation counter. The BF_3-counter was always counting slow enough to have negligible counting losses. The scintillation counter, on the other hand, had a counting rate that increased from a low value ($< 10^4$ cps) to a value an order of magnitude higher than the ones encountered in the experiments. Counting corrections never amounted to more than a few per cent.

Other conditions being equal, the experimental results did not differ more than statistical errors whether the scintillation counter was placed at the surface or inside the shield or in the thermal column. Corrected results are plotted for a number of experimental situations (reactivities) in Fig. 3.

Theoretical Approach

The general features of the data can be interpreted by using a simple theory of reactor kinetics. It will be assumed that the neutron density in the reactor can be represented as a product of a space- and a time-dependent function. When dealing with average neutron densities over the reactor, this assumption is approximately correct if the induced variations in the multiplication factor are small. How small the variations need be is dependent on factors such as the kind of averages observed, the locality and extension of the region over which the neutron reproduction is changed, etc. In these experiments, neutron waves are generated when the rabbit, which represents a sink of neutrons, moves towards the surface of the reactor. However, the effects of these waves are probably averaged suitably by "looking" into the reactor with a counter about 50 cm above the rabbit track and at a large distance from the disturbance (Fig. 1).

The over-all response of a reactor to a step-function change in the multiplication factor will be considered first. Temperature effects and the build-up of neutron-absorbing fission products will be neglected. If the effective multiplication factor, k_{eff}, is suddenly brought above unity by an amount k_{ex}, the consequent rate of change of the thermal-neutron density in the reactor will, according to diffusion theory, be

$$\frac{\partial n(r,t)}{\partial t} = \frac{k_{ex}}{l^*}\, n(r,t) - \sum_i \frac{\partial c_i(r,t)}{\partial t}\, \bar{P}_\infty(B^2) \quad (1)$$

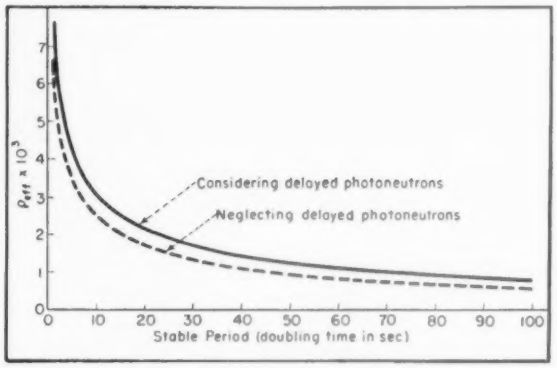

FIG. 4. Reactivity vs stable period for $l^* = 2 \times 10^{-3}$ sec. Eq. 6 and data from Table 1 used for dashed curve. Delayed photoneutrons have longer lifetime than delayed neutrons. For given reactivity, period of D_2O reactor is longer than graphite reactor's

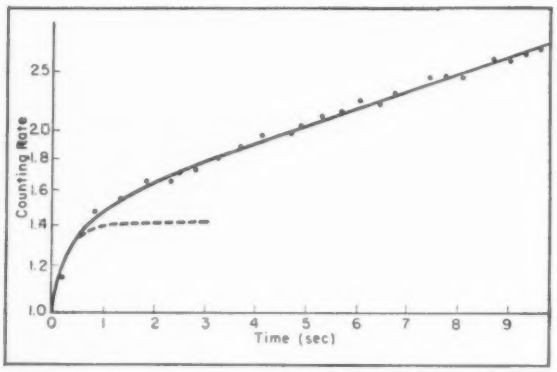

FIG. 5. Comparison of theory (solid curve) using Eq. 3 and constants from Table 2, with experiments (points) for $k_{ex} = 0.0025$. Dashed curve calculated from Eq. 8 for initial power rise

where l^* is the average lifetime of a neutron in the reactor, $\bar{P}_\infty(B^2)$ is the three-dimensional Fourier transform of the infinite slowing down kernel for neutrons in a fundamental spatial mode corresponding to the buckling B^2 (3). It is assumed to be identical for prompt, delayed and photoneutrons. The density of the ith delayed neutron emitter, $c_i(r,t)$, obeys the equation

$$\frac{\partial c_i(r,t)}{\partial t} = \frac{k}{p}\beta_i \Sigma_a v n(r,t) - \frac{c_i(r,t)}{\tau_i} \qquad (2)$$

where β_i is the ratio of the number of delayed neutrons of mean life τ_i to the total number of neutrons emitted in fission, k is the infinite multiplication factor, p the resonance escape probability, and Σ_a the average macroscopic cross section for thermal neutrons of average velocity v.

Among the delayed neutron emitters will be included the fission products that emit neutrons subsequent to the emission of β-particles, and the γ-ray emitters with an energy sufficient to produce photoneutrons in the heavy water (>2.2 Mev). The geometry of the reactor determines the probability of γ-rays producing photoneutrons before suffering energy loss by Compton scattering or pair production. Rough estimates indicate that about 10% of the γ-rays are lost by collisions in the uranium and aluminum before they are able to get out of the fuel rods into the heavy water. Bernstein *et al.* (4) have measured the total yield of photoneutrons in heavy water from a small sample of fission products. Extrapolated values of the yield in an infinite sphere of D_2O are given in Table 1. The characteristics of the delayed neutron emitters as measured by Hughes *et al.* (5) are also shown. The figures in Table 1 are uncertain by a few per cent.

The terms under the summation sign in Eq. 1 should include a space-dependent correction factor for the efficiencies of the neutrons originating from the respective fission fragments, as compared to the prompt neutrons, in maintaining the chain reaction. However, the uncertainties in the experimental values of β_i and τ_i are so large that no attempt has been made to make a detailed calculation of the corrections. The values in Table 1 are used instead.

The simultaneous differential equations (Eqs. 1 and 2) can be solved by the expansions

$$n(r,t) = n(r)\sum_s A_s e^{t/T_s}$$
$$c_i(r,t) = c_i(r)\sum_s c_{is} e^{t/T_s} \qquad (3)$$

Inserting these in Eqs. 1 and 2, a relation between the reactivity, $\rho_{eff} = k_{ex}/k_{eff}$, and the time constants, T_s, of the reactor is obtained. If use is made of the relations

$$k_{eff} = \frac{\frac{k}{p}\bar{P}_\infty(B^2)}{1 + L^2B^2} \qquad (4)$$

and

$$l^* = 1/\Sigma_a v(1 + L^2B^2) \qquad (5)$$

where L is the diffusion length, then

$$\rho_{eff} = \frac{l^*}{k_{eff}T_s} + \sum_i \frac{\beta_i \tau_i}{\tau_i + T_s} \qquad (6)$$

For a given positive value of ρ_{eff} there are $i + 1$ roots of Eq. 6; one is positive (the stable period) and i are negative. The calculated stable period is plotted in Fig. 4.

To find the coefficients A_s and C_{is}, the boundary conditions at $t = 0$ are needed. The experimental procedure consists of stabilizing the reactor power level at criticality, and then suddenly increasing the reactivity by expelling the cadmium absorber. Due

TABLE 1—Delayed Neutron Characteristics

Delayed neutrons		*Delayed photoneutrons*	
Half-life (sec)	*Yield ($\beta_i \times 10^5$)*	*Half-life (sec)*	*Yield ($\beta_i \times 10^5$)*
0.05	25	2.5	78
0.43	85	41	24
1.52	241	144	8.4
4.51	213	462	4.0
22.0	166	1,620	2.5
55.6	25	5,940	2.8
		15,840	0.39
		190,800	0.12
		1,105,200	0.05

to the long lifetime of the delayed neutron emitters compared to l^*, the delayed neutrons are emitted at a constant rate at $t = 0$ $(\partial c_i(r,o)/\partial t = 0)$. Table 2 records some typical values of T_s and A_s (see also Fig. 5).

Before comparing these theoretical results with experiments, we shall discuss somewhat further the variations of the neutron density during a time of about 10^{-1} sec after the reactivity is increased. Since the lifetimes of the delayed neutron emitters are long compared to 10^{-1} sec,* the delayed neutrons will be emitted at a nearly constant rate during the time considered. Thus the reactor has been running at a steady power (neutron density = n_o) up to the time when the effective multiplication factor is made positive by an amount k_{ex}. During the following few tenths of a second the reactor contains a constant source of neutrons due to the previously accumulated delayed neutron emitters. Since the response of the reactor takes place as if the delayed neutrons did not contribute to the excess multiplication, the effective increase in k is $k_{ex} - \beta k_{eff}$. Thus, the rate of change of the neutron density during an initial time of the order of 10^{-1} sec is

$$\frac{dn}{dt} = \frac{k_{ex} - \beta k_{eff}}{l^*} n + \frac{\beta k_{eff}}{l^*} n_o + S \quad (7)$$

where a source term S is included. If k_{ex} = constant, integration yields

$$\frac{n}{n_o} = 1 + \left[\left(k_{ex} + \frac{Sl^*}{n_o} \right) \Big/ (\beta k_{eff} - k_{ex}) \right] \left\{ 1 - \exp\left(- \frac{\beta k_{eff} - k_{ex}}{l^*} t \right) \right\} \quad (8)$$

Thus, the neutron density increases with a time constant $l^*/(\beta k_{eff} - k_{ex})$ initially. The density approaches an asymptotic value $(\beta k_{eff} + Sl^*/n_o)/(\beta k_{eff} - k_{ex})$. The appropriateness of this description is demonstrated in Figs. 5, 6 and 7, where the dashed lines have been calculated from Eq. 8.

Comparison

Due to the finite time of flight of the rabbit through the reacting core ($\leq$0.06 sec), the multiplication factor does not vary like a true step-function of time. If Eq. 7 is integrated with k_{ex} as a function of time, an estimate of the influence of this perturbation on the variation in the neutron density is obtained (*6*). With this procedure it was found that the increase in n/n_o during the transit time of the rabbit was less than 10% of the asymptotic value of the initial rise as given by the time-independent solution of Eq. 7.

The further variation of the thermal neutron flux with time is initially well represented by Eq. 8. With $\beta k_{eff} \simeq \beta = 0.0086$, the value of k_{ex} can be determined from the amplitude of the initial increase of the neutron density ($\simeq \beta/(\beta - k_{ex})$, for $S = 0$). The excess multiplication factors deduced in this way have been compared with the values obtained from the stable periods according to Eq. 6 or Fig. 4. The agreement is very good.

The time constant of the initial rise, together with the preceding values of k_{ex}, yielded the average effective lifetime of a neutron in the reactor l^*. Best agreement of experiments and theory was obtained for $l^* = 2 \times 10^{-3}$ sec. Consider the case in Fig. 6 as an example. The broken curves were calculated according to Eq. 8 with $l^* = 1.5 \times 10^{-3}$ sec and 2.5×10^{-3} sec. The best fit is undoubtedly obtained for $l^* = 2 \times 10^{-3}$ sec. Uncertainty is estimated as less than 10%.

The influence of the steady photoneutron background (*2*) was noticeable when the initial power level of the reactor was below 500 watts. Figure 7 shows an example. From the stable periods it is found that $k_{ex} = 0.001$ for both cases. The steady background source of photoneutrons was 0.04 watts (*2*). Thus, initially

$$k_{ex}{}^0 = -Sl^*/n_0 = \begin{cases} -0.04/100 = -0.0004 & \text{for } P_0 = 100 \text{ watts} \\ -0.04/500 = -0.00008 & \text{for } P_0 = 500 \text{ watts} \end{cases}$$

and the amplitudes of the initial increase become (Eq. 8)

$$\frac{n}{n_0} = \frac{\beta - k_{ex}{}^0}{\beta - k_{ex}} = \begin{cases} 1.18 \text{ for } P_0 = 100 \text{ watts} \\ 1.14 \text{ for } P_0 = 500 \text{ watts} \end{cases}$$

in agreement with the experiments.

* * *

The authors wish to thank Mr. K. Skarsvåg and Mr. S. Thue for help with the experiments, and the calculating office at the Norwegian Defense Research Establishment for performing the numerical computations.

TABLE 2—Time Constants, T_s, and Coefficients, A_s, For Various Delayed Neutron Groups, s, When $\rho_{eff} = 0.0025$

s	T_s	A_s
1	14.7	1.93
2	−0.0488	−0.0016
3	−0.195	−0.278
4	−0.516	−0.0815
5	−2.03	−0.0498
6	−3.04	−0.0635
7	−11.83	−0.340
8	−38.6	−0.0343
9	−52.4	−0.0289
10	−140	−0.223
11	−455	−0.0138
12	−1,600	−0.0095
13	−5,880	−0.0091
14	-1.58×10^4	−0.0017
15	-1.91×10^5	−0.0005

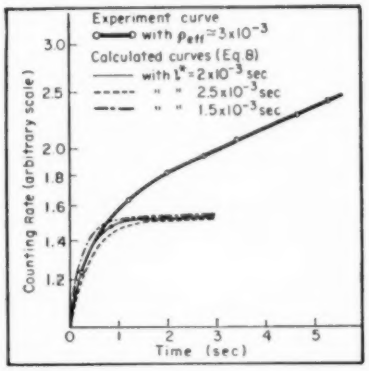

FIG. 6. Time constant of initial rise in power level

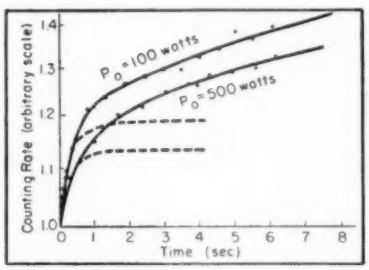

FIG. 7. Variation of neutron-counting-rate with time after ejection of rabbit ($k_{ex} = 10^{-3}$), dashed curves from Eq. 8

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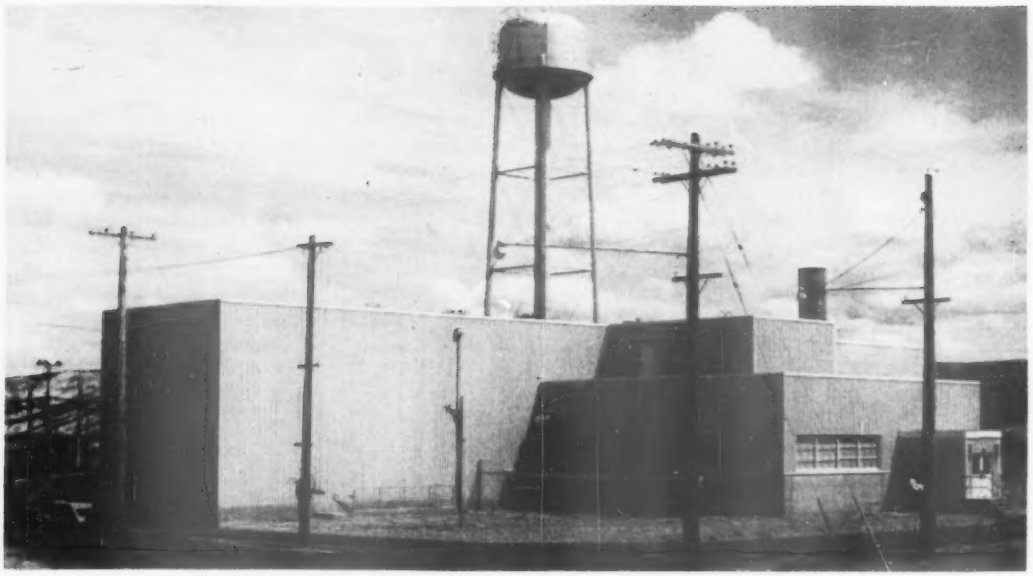
* The delayed neutron emitters with a lifetime shorter than 1 sec will contribute to the initial fast rise in power. However, their effect is negligible because of their low abundance.



The New Radiometallurgy Laboratory

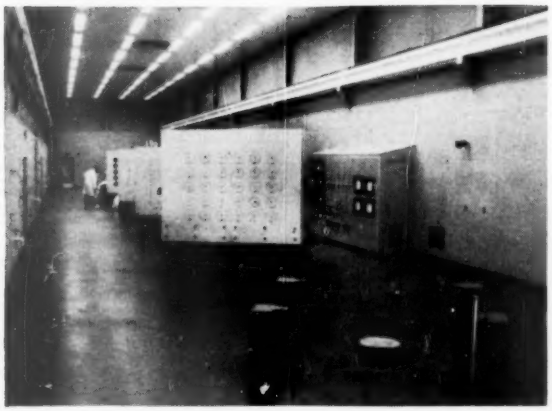
1 MAIN WORK AREA of new Radiometallurgy Building is 173-ft "canyon" that lies at right angles with two wings. One-story building has floor space of more than 14,000 ft²

AT HANFORD WORKS, operated in Richland, Wash., by General Electric for the AEC, an $850,000 structure provides complete facilities for metallurgical studies of irradiated metals. Prime target for research in the new building will be solution of problems encountered in fuel slugs from the Hanford reactors: fuel structure, bonding, metal preparation and canning, and deterioration of the fuel element.

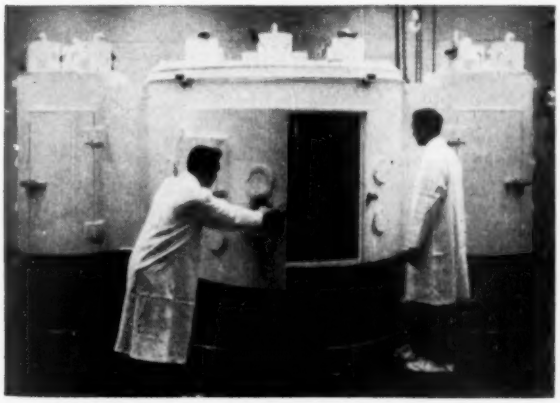
To accomplish this purpose, samples of intermediate and high activity levels must be handled. Thus the major equipment in the new building is an array of multicurie cells. The high-level cell will be used for specimen measurement: length, diameter, warp, fuel density. One intermediate-level cell will be used for metallographic studies: grinding, polishing, etching, photomicrography, and microscopy. The other swill be used for physical and chemical testing of small samples: electrical resistivity, thermal conductivity, density, hardness, impact testing, and corrosion studies.

Each cell has its own ventilating and filtering system, as do the decontamination cell and the dry storage cell. Ventilation of the general working areas is accomplished with machinery located in the basement.

In addition to the equipment pictured on these pages, the building also contains a wet storage cell that keeps irradiated samples under 10 ft of water; a 15-ton crane over the canyon; storage rooms for test equipment, a machine shop for "hot" parts; photographic darkroom; chemical preparation room; health instrument room; and personnel and office facilities.

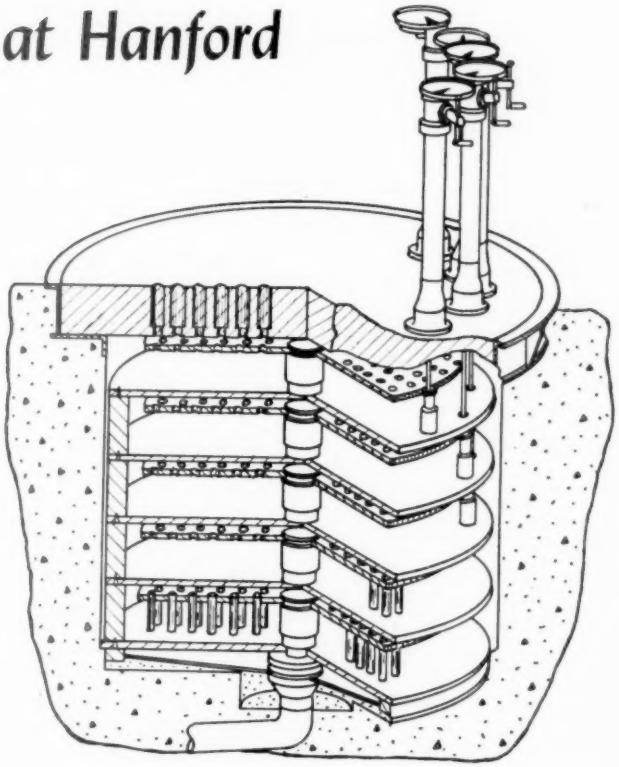


2 FOUR MULTICURIE CELLS are installed; foundations (foreground) are provided for four more. Three cells, for intermediate-level work, have Meehanite walls 10½ in. thick. Top plates, doors are dovetailed. Single high-level cell has walls 15 in. thick. Ports can be used for inserting samples, for holding viewing windows, manipulators, etc, or can be closed with solid plugs. Patch panels along walls provide 120–480 volt a-c, 24 and 120 volt d-c

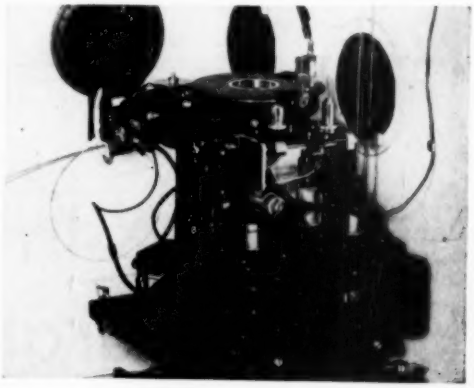


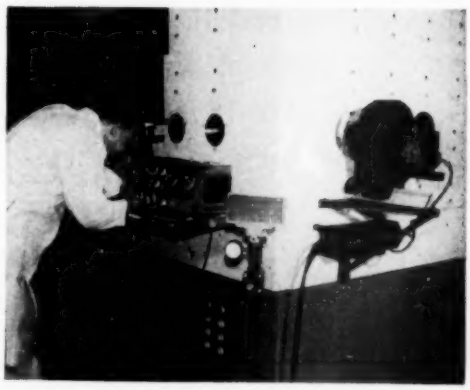
3 DECONTAMINATION CELL is actually three connected units, one 8 ft in diameter, other two, 4 ft. Smaller units are used primarily for decontaminating parts of subassemblies removed from equipment in large cell. Parts are placed on 1-in.-thick steel disks that rotate within each cell. Specially designed manipulators are used for cleaning by remote control. In same room is stainless-steel hood for handling very low level decontamination directly

at Hanford



4 DRY STORAGE CELL is recessed in canyon floor. Five perforated steel disks can be rotated so that holes line up for insertion or removal of individual radioactive metallurgical specimens. Lead-glass window permits accurate sample positioning. About 7½ ft in diameter, 6½ ft deep, unit holds up to 700 four-pound samples, provides adequate radiation shielding





5 METALLOGRAPH within intermediate-level cell (top) is precisely controlled from panel outside (below). Cell floor is covered with aluminum dish-like pallet to provide greater control over contamination, also provide surface on which equipment can be placed in cell with remote-control fork-lift truck

TABLE 1—Weight Changes (Grams) in Male Mice (3-Day Period)

First series: total 10 mice				*Second series: total 20 mice*				
Controls		*X-irradiated (1,250 r)*		*Controls*		*X-irradiated (1,250 r)*		
	No food final 24 hr	*	*No food final 24 hr*		*No food final 24 hr*		†	*No food final 24 hr*
28.3	24.4	31.7	26.8	28.2	26.4	28.9	26.1	22.7
30.3	25.6	29.6	26.4	29.9	27.9	28.9	27.0	24.0
28.0	22.8	28.5	23.8	30.2	27.8	27.9	24.9	22.5
30.5	26.9	30.0	24.6	34.4	31.5	29.5	24.0	21.7
30.3	26.3	29.2	23.6	31.4	26.6	29.4	26.2	23.7
—	—	—	—	27.8	28.5	31.7	29.3	25.8
147.4	126.0	149.0	124.9	25.5	23.5	28.1	26.3	23.5
Av. 29.5	Av. 25.2	29.8	25.0	29.4	27.8	29.5	26.0	23.7
				29.3	26.3	28.0	24.8	22.6
				29.2	28.5	30.7	27.2	23.2
				—	—	—	—	—
				295.3	274.8	292.6	261.8	233.4
				Av. 29.5	27.5	29.3	26.2	23.3
Average loss 4.3 gm		Average loss 4.8 gm (3 days)		Average loss 2.0 gm		2.1	2.9 5 gm	

* Weighed just before X-irradiation to 1,250 r.
† Weighed 2 days after irradiation but before depriving of food.
Note: If one assumes no weight loss of the controls, prior to food deprivation, then X-irradiation caused the experimental mice to lose 2.1 gm or 7 % of their weight in two days.

Effect of X-Irradiation on Tissue Hydration in the Mouse

Contrary to expectation, percentage change of total body water of mice submitted to 1,250-r X-radiation appears secondary to decrease in the aggregate dry weight of 5–18%. Although adult nervous tissues have been considered radioresistant, the dry weight of the brain increases by 7.7–14.3%

By ROBERTS RUGH
Radiological Research Laboratory
College of Physicians and Surgeons
Columbia University
New York

IN ONE WAY OR ANOTHER, hydration (or dehydration) has been implicated in the syndrome following high-level, whole-body X-irradiation of animals. Nausea, vomiting, diarrhea, edema, a fall in blood pressure, and shock all involve changes in hydration. At the cellular level there is the shrinking or swelling of nuclei and cells, and alterations in the cytoplasmic sol-gel balance, which may be related to mitotic effects, changes in permeability and ionic balance.

The most radiosensitive tissues of the adult are the vascular, lymphoid and hematopoietic tissues, which are highly fluid. The embryo, which invariably has a higher percentage of water than does the adult, is the more radiosensitive. Within the embryo, those cellular elements that are undergoing the most rapid differentiation, such as the neuroblasts, are in a more fluid state than is the neuron into which it differentiates, and is some 10,000 times as radiosensitive.

Finally, there are many who are convinced that the instantaneous dis-

TABLE 2—Wet Weight in Grams of Organs (Male Mice)

Group of five mice				*Group of ten mice*		
Controls: Average	*X-irradiated: Average*	*Change*	*Tissue*	*Controls: Average*	*X-irradiated: Average*	*Change*
4.1	2.8	−	Skin	3.9	2.9	−
1.56	1.29	−	Liver	1.44	1.31	−
3.08	*4.91*	+	Intestines	3.97	3.7	−
0.48	0.41	−	Kidneys	0.51	0.39	−
0.007	0.006	−	Adrenals	0.009	0.007	−
0.2	0.09	−	Spleen	0.15	0.04	−
0.05	*0.062*	+	Thymus	0.044	*0.05*	+
0.38	*0.41*	+	Brain	0.40	*0.43*	+
0.27	*0.29*	+	Muscle	0.29	0.28	−
0.14	*0.17*	+	Bone	0.15	*0.15*	0
13.4	13.4	0	Carcass	14.5	12.8	−
Average gain of 0.18 gm				Average loss of 3.5 gm		

Note: Total weight of mice compared with aggregate of organs after dissection:

	Before dissection	*After*	*Loss*	*% Loss*
Controls (5)	126.0	118.4	7.6	6
X-irradiated (5)	124.9	119.3	5.6	4.5
Controls (10)	274.8	255.6	19.2	7
X-irradiated (10)	233.4	220.5	12.9	5.5

The maximum loss of 7% between the weight of the living animals and the aggregate weight of all dissected organs may represent blood, lymph and evaporation loss which could not be avoided. Since the range was quite uniformly between 4.5–7% for all groups, the factor is within the limits of acceptable variation and may be disregarded.

sociation of water into OH^- and H^+ and the brief recombination of its ions into peroxide may be the major deleterious effect resulting from the exposure to ionizing radiations. This does not deny the importance of enzymes, which must function in solution, nor the effect on chromosomes, which may be secondary. One is inevitably led to suspect that alterations in water (dissociation, balance, transport) may be the cause, the corollary, or the result of exposure to ionizing radiations at levels approaching lethality.

One approach to this problem is to determine the absolute and the relative changes in water in those tissues demonstrated to be the most radiosensitive. This study presents the data on changes in wet and dry weight and percentage of water in ten separate organs, as well as the remaining carcass, three days after exposure of Swiss male mice to a 100% lethal dose of X-radiation. This dose was 1,250 r.

Materials and Method

Male Swiss mice of 9–12 weeks of age and of uniform weight were used. This provided young but mature animals without the fluctuating hydration changes normally accompanying estrus. Two sets of experiments were conducted, the first involved 10 mice (5 controls and 5 experimentals), and the second twice as many animals.

All mice were from our inbred colony. They were maintained on food and water *ad libitum*, except that for 24 hr before sacrifice all were deprived of food to evacuate the gut and reduce the animal to its essential tissues.

Since warm tissues dehydrate in air, the mice were dissected rapidly after severing the spinal cord, and the tissues were placed on previously weighed filter paper (to absorb all fluids) and weighed on a Gramatic balance to the third place. This was true except for the skin and remaining carcass, which were relatively so heavy that they were weighed on a regular laboratory balance. The tissues were taken in the following order: skin (from above the eyes to ½ in. of the tail), liver (entire organ and gall bladder), gut (large and small intestine, stomach and pancreas), kidneys (two from each animal), adrenals (two from each animal), spleen (entire), thymus (entire), brain (entire), bone (tibia), muscle (gastrocnemicus), and carcass (remainder of entire animal after preceding elements had been removed).

The tissues were weighed in stoppered weighing bottles. These bottles, each containing all the similar tissues from 5 (or 10) male mice, were then opened and placed in an incubator at 100° C for seven days. They were then stoppered, cooled, and weighed. Further dessication was achieved by placing the dried tissues in a dessicator over anhydrous calcium chloride for an additional period of 3–7 days. The minimal weight recorded under these various treatments was considered to be the absolute dry weight of the tissues.

Prior to excision of the tissues, each mouse was individually weighed at the beginning of the experiment, at 2 days following exposure to ionizing radiations, and on the following day after 24 hr of starvation. Thus, the data include the effect on total body weight of a lethal exposure to ionizing radiations in addition to the weight change due to deprivation of food, which data is balanced out by effects on the controls. Whether or not the

exposed mice were anoretic, they and the controls did not ingest any food for 24 hr prior to dissection.

The X-ray facilities used were the Quadrocondex constant-potential machine held at 210 kvp, 15 ma, with 0.28 Cu and 0.50 Al filtration, distance of 30 cm, with air dose at level of center of the body of the mice of 257 r/min. The total exposure was 1,250 r in 4 min. 51.5 sec. Immediately after exposure of animals (5 at a time in a plastic cage), they were returned to their regulation cages in the animal room.

Observations and Data

Since the X-irradiated mice were exposed to a 100% lethal dose of 1,250 r, and some might die as early as 3½ days post-irradiation, it was decided to determine the hydration changes as of 3 days. It is true that some mice might well survive this first critical period, but it is probably correct to assume that even those few mice would exhibit radiation changes in their tissues.

The mice for each experiment were selected on the basis of similarity in weight. The average weight for each initial group was 29.5 and 29.5 gm for the controls and 29.8 and 29.3 for those to be X-irradiated. Within the groups, the maximum variation was 25.5–34.4 gm. This variation in weight was found among the larger control group where the average was still 29.5 gm.

Whole-body weight changes. After 48 hr, food was removed from all cages (controls and experimentals). It is presumed that there was a reduction of food intake by the X-irradiated mice shortly after exposure. The loss in weight due to the final 24-hr deprivation was probably similar for both the controls and experimentals. Further, the fact that anorexia is a frequent consequence of radiation exposure, the controls were subjected to "enforced anorexia" so far as ingestion was concerned, during the final 24 hr. Thus, the weight changes of controls and experimentals are directly comparable for this period.

During the final period of 24 hr of food deprivation, the group of 10 controls lost an average of 2.0 gm, which represented 6.1% of their original weights. During the same final period, the group of 10 mice exposed to 1,250 r lost 2.9 gm. This represented a loss of 11% by weight. Thus, the loss of weight due to food deprivation for the final 24 hr was not very different for the controls and the X-irradiated mice.

Assuming that food deprivation affected all mice alike, then we find that the controls lost 4.3 and 2.0 gm while the X-irradiated (comparable) mice lost 4.8 and 5 gm. These losses are 14.6% and 6.1% for the controls and 16.2% and 16.9% for the X-irradiated mice over the three-day period, inclusive of the 24-hr food deprivation period. There is evidence, therefore, of some weight loss within the first 48 hr following X-irradiation. The net loss attributable to irradiation in the larger group of 10 mice was therefore 5.9% of the original weight, lost during the three-day post-irradiation period (see Table 1).

Wet weight of mouse organs. In Table 2, in the first series of 5 mice controls compared with 5 experimentals, there was a net gain of 0.9 gm of the aggregate of tissues while the same (living) animals had shown an aggregate total body loss of 0.2 gm (see Table 1). In the group of 10 mice, there was a net loss of 3.5 gm per mouse in weight of the aggregate of irradiated tissues as compared with those of the controls (Table 2). The animals from which these tissues had been taken had previously (Table 1) indicated an average body weight loss of some 0.2 and 4.2 gm, prior to the water determinations.

In the note appended to Table 2, it is indicated that the percentage loss in total weight of the control and X-irradiated mice, when the total body data are compared with the weight of the aggregate of organs, falls within the range of 4.5–7%. In other words, evaporation plus blood and lymph loss during the process of excision of

TABLE 3—Dry Weight of Organs (Male Mice)

Total weight (five mice)					*Total weight (ten mice)*			
Control	*X-rayed*	*Change*	*% Change*	*Tissue*	*Control*	*X-rayed*	*Change*	*% Change*
8.4	6.5	1.9	22.6	Skin	18.00	13.4	4.6	25.5
2.25	1.76	0.49	21.8	Liver	4.25	3.72	0.53	12.5
3.27	2.76	0.51	15.6	Intestine	8.70	5.77	2.93	33.7
0.604	0.506	0.098	16.0	Kidney	1.33	1.04	0.29	21.7
0.017	0.0104	0.0066	38.0	Adrenal	0.05	0.03	0.02	40.0
0.214	0.113	0.101	47.0	Spleen	0.36	0.097	0.263	73.0
0.545	0.007	0.538	98.7	Thymus	0.110	0.014	0.081	74.0
0.404	0.462	+0.058	+14.3	Brain	0.86	0.93	+0.066	+ 7.7
0.348	0.370	+0.02	+ 6.3	Muscle	0.75	0.736	0.014	1.8
0.379	0.448	+0.069	+18.2	Bone	0.85	0.853	+0.003	+ 0.3
21.0	20.6	0.4	1.9	Carcass	48.9	42.1	6.8	14.0
35.44	33.44	−2.0	= 5.6%		84.16	68.69	−15.47	= 18.3%

Note: Over-all loss in dry weight following X-irradiation is misleading because of the high percentage loss in certain tissues (thymus, spleen, adrenal) which are low in total weight, and slight gain in dry weight of the heavier brain, bone, and (in one experiment) muscle.

TABLE 4—Water Determination in Tissues

Controls				*X-rayed (1,250 r)*			
Wet weight	*Dry weight*	*% water*	*Tissue*	*Wet weight*	*Dry weight*	*% water*	*% change in tissue*
Water determinations in tissues of five male mice (average)							
4.1	1.68	59	Skin	2.8	1.3	54	− 5
1.56	0.45	71	Liver	1.3	0.353	73	+ 2
3.08	0.65	79	Intestine	4.9	0.55	89	+10
0.478	0.12	75	Kidney	0.414	0.101	76	+ 1
0.0074	0.0034	54	Adrenal	0.0064	0.0021	67	+13
0.195	0.0427	78	Spleen	0.0858	0.0227	74	− 4
0.0429	0.0109	75	Thymus	0.0062	0.0012	81	+ 6
0.384	0.0808	79	Brain	0.43	0.0924	78	− 1
0.271	0.0695	74	Muscle	0.295	0.074	75	+ 1
0.141	0.0757	47	Bone	0.166	0.089	46	− 1
13.40	4.20	69	Carcass	13.4	4.1	70	+ 1
23.67 gm	7.38 gm	69%		23.8 gm	6.68 gm	72%	
Absolute water = 69%				Absolute water = 72%			
Water determinations in tissues of ten male mice (average)							
3.9	1.8	54	Skin	2.89	1.35	53	− 1
1.44	0.43	72	Liver	1.30	0.37	72	− 0
3.97	0.87	78	Intestine	3.70	0.58	84	+ 6
0.51	0.13	74	Kidney	0.40	0.10	75	+ 1
0.0098	0.0054	45	Adrenal	0.0070	0.0030	57	+12
0.157	0.036	77	Spleen	0.0407	0.0097	76	− 1
0.0445	0.0107	76	Thymus	0.0050	0.0014	72	− 4
0.4010	0.0865	79	Brain	0.4263	0.0926	78	− 1
0.2855	0.0754	74	Muscle	0.2842	0.0736	78	+ 4
0.1506	0.0851	44	Bone	0.1517	0.0846	45	+ 1
14.53	4.89	66	Carcass	12.80	4.20	67	+ 1
25.47 gm	8.42 gm	67%		22.0 gm	6.87 gm	69%	
Absolute water = 67%				Absolute water = 69%			

Note: Consistent high increase in percentage of water in adrenal glands and intestines.

the various organs amounted to essentially the same factor for irradiated and control mice, and can be disregarded.

While it must be emphasized that it is physically impossible to compare the identical organ under control and X-irradiated conditions, by selecting mice of comparable age, sex, and weight, and using groups of 5 or 10 for each set of readings, we approach reproducible data. In Table 2, the underlined figures are those that are either unchanged or have shown an increase in wet weight following X-irradiation. In both series the thymus, brain, and bone showed an increase in wet weight while the intestines, muscle, and remaining carcass showed some slight increase in one of the series only. All other tissues showed a decrease, the greatest percentage decrease in wet weight of organs was seen in the spleen and the skin.

Dry-weight changes. The dry weight of the X-irradiated tissues (Table 3) aggregated less than those of the controls by 5.6% (5 mice) and 18.3% (10 mice). Again, these comparative values are based, not on the identical tissues, but similar tissues from carefully selected control and experimental animals. One must therefore conclude that the aggregate dry weight of all the tissues of the mice three days after X-irradiation was less than that of the controls. The greatest percentage loss was in the thymus, spleen, and adrenal, with intestine, skin, and liver following (in that order). Since percentage loss in water does not reflect the absolute loss, it might be pointed out that the skin lost the most water with the intestines next.

Curiously, there was a pronounced *increase* in the amount of dry tissue in the brain and bone, and (in the group of 5 mice) in muscle. The brain tissue showed an increase of 7.7 and 14.3% in dry weight over the comparable controls, as a result of X-irradiation.

Water determinations in tissues. The percentage of water in the various tissues of control and X-irradiated mice was determined on the basis of the relationship of the wet and dry weights alone. On this basis (see Table 4), X-irradiation brought about an appreciable percentage increase in water content of the adrenal glands, the intestines, and the thymus (one experiment). There was a decrease in the skin and spleen, while the other organs were only slightly changed.

In handling and examining an X-radiated and moribund mouse three days after exposure to a 100% lethal dose of 1,250 r, one is invariably impressed with an appearance of dehy-

dration. The subcutaneous tissues are dry and shiny. It has been shown that such mice have lost weight, but, according to Table 4, the water percentage of all of the animals' tissues shows a very slight increase. There has been a shift of water percentage from the skin and the spleen and in favor of the adrenal and intestines particularly. But the shifting does not alter appreciably the over-all water percentage of the aggregate of tissues.

A direct comparison of the water percentages of the control and X-irradiated tissues is given in Table 4. Of all, the adrenals and the intestines, in both series, showed from 6–13% increase in water percentage.

Wet and dry weight changes. When one compares the percentage (rather than absolute) changes in wet and dry weights of the various tissues following the lethal exposure to X-radiations (Table 5), it is immediately obvious that the dry-weight changes are far in excess of the changes in water percentage.

The maximum wet-weight change is an increase in the adrenal gland by 13%, while the maximum dry-weight change is a reduction in the thymus by 98%, with the spleen following by a drop in dry weight of a maximum of 73%. Muscle shows the least change in wet and dry weight combined.

TABLE 5—Percentage Wet and Dry Weight Changes, 3 Days Following Lethal Exposure to X-Rays

Dry-weight change			*Wet-weight change*	
Five mice	*Ten mice*	*Tissue*	*Five mice*	*Ten mice*
−22.6%	−25.5%	Skin	−5%	−1%
−21.8	−12.5	Liver	+2	−0
−15.6	−33.7	Intestine	+10	+6
−16.0	−21.7	Kidney	+1	+1
−38.0	−40.0	Adrenal	+13	+12
−47.0	−73.0	Spleen	−4	−1
−98.7	−74.0	Thymus	+6	−4
+14.3	+ 7.7	Brain	−1	−1
+ 6.3	− 1.8	Muscle	+1	+4
+18.2	+ 0.3	Bone	−1	+1
− 1.9	−14.0	Carcass	+1	+1

Note: Percentage changes in dry weight far exceed those in wet weight following X-irradiation.

Review of Previous Papers

The incentive for this investigation was the appearance of general body dehydration in moribund animals following X-irradiation. It was further encouraged by evidence from various research approaches that the fluid environment was somehow involved in radiation toxicity. Before discussing the findings of this paper, a brief review of the pertinent papers should be made to clarify the issue as of the present.

Many rat tissues showed an increase in water content after high single and repeated doses of X-rays (*1*) and after a series of small daily doses (*2*).

France (*2*) used the thiocyanate ion method to determine the changes in water content and distribution in mice after chronic and whole body X-irradiation, concentrating on muscle, plasma, and the remaining carcass because "abnormalities in fluid distribution and metabolism are typical consequences of X-irradiation," and "the fluid unbalance is characterized by an edema which is indicative of water retention, as well as by net water loss as shown by a negative water balance." France found evidence of an increase in extracellular fluid and a decrease in intracellular fluid following X-irradiation, and yet the total body water percentage increased only slightly from 66.3% in the controls to 71.1% 5 days after 700-r X-ray whole-body exposure. Both muscle and plasma showed a slight (0.9% and 0.5%) increase in water content. France stated: "Most animals show a decrease in urine output after irradiation which is accompanied by a greater decrease in water intake; consequently they go into a state of negative water balance." In view of the findings of this paper, it is the more significant that France predicted: "The net water loss observed after irradiation might lead to the belief that the animals became dehydrated after X-irradiation. But, as the measurement on water content and water distribution show, there was a relative water retention after midlethal and sublethal amounts of irradiation. There must be, consequently, a greater loss of solids in proportion to the water loss than in the normal animal, and perhaps a decrease in insensible water loss."

With respect to dehydration and protection against X-irradiation, Petry (*3*) and Henshaw and Francis (*4*) found that dehydrated seeds were more radioresistant and Failla (*5*) suggested that this might bear some relationship to tumor sensitivity. France reported that water restriction did prolong the life but did not increase survival of irradiated mice, and "as soon as they were given water *ad libitum*, they drank large amounts and most of them died within the next 3 days"; "these findings suggest that negative water balance after acute irradiation of the entire organism is of survival value." A final suggestion of France is interesting: "Since the increase in body water was present almost a year after an acute X-irradiation, and after daily chronic low-level exposures, the changes may be akin to the aging process."

Patt *et al.* (*6*) found a post-irradiation increase in adrenal weight, as much as 55% in four days after 650 r to mice. They found the adrenal to increase in dry weight (130% at death), and "the per cent water is thus almost equivalent at all sacrifice periods even though the wet weight is increasing." "One may conclude only that the adrenals do respond after X-irradiation in a manner not unlike that described for other conditions of stress of the organism." The spleen was reduced to 25% of its original weight at the time of death of mice following 900-r X-irradiation. The body weight showed little and the kidney no change.

Bowers and Scott (*7*) claimed a loss in dry weight following irradiation of

all organs studied and stated: "It is apparent that there is no correlation between the changes in percentage water content and in the dry weight of organs after irradiation. . . . The early loss of dry weight in lymph nodes and gastrointestinal tract emphasizes the rapid decrease in tissue substance from specific radiation injury in these organs, while the later decrease in testis, liver, and kidney probably reflects in part loss of tissue substance from the total anorexia that accompanies whole-body irradiation injury. The striking increase in dry weight of the spleen is puzzling." We found a decrease of 47 and 73% in dry weight of the spleen. Bowers and Scott finally write: "Percent loss of dry weight per day is in general most pronounced in radiosensitive tissues."

Smith *et al.* (*8*) said: "Exposure to X-radiation did not accelerate the rate of weight loss or hasten the death of rats that were completely deprived of food. . . . Neither did X-irradiation influence the water content of the gastrocnemius muscle or of the entire carcass of the starved rat, indicating that water retention was not responsible for the failure to find an increased rate of weight loss in the starved-irradiated rat." They believe that the water content of the entire carcass as of the gastrocnemius muscle of the starving rat was unchanged by X-irradiation, and that total body X-irradiation did not affect metabolism.

Nims and Sutton (*9*) found that immediately after irradiation of fasting rats there was a period of polydipsia, followed by a drop in water intake to fasting levels. They would not go so far as to correlate water intake with radiation exposure as a possible dosimeter.

Cook *et al.* (*10*) compared the tedious drying versus the rapid titration method of water determination in muscle, liver, and brain. Their results were essentially the same, indicating that the slow drying method used in this study was nevertheless accurate.

Conrad (*11*) found little change in the water content of rat intestines following 500-r X-rays (LD 30/30), but with the mouse they found a consistent increase in water content. However, he stated: "It would not seem that edema plays any significant role in the enzyme activity changes after irradiation." Later (*12*), Conrad found that the stomach, small and large intestines showed a loss of weight during the first 3 or 4 days after X-irradiation of the rat, which loss was greater than the body-weight loss. He did not attribute the weight changes to edema or dehydration of the tissues," but were in large part due to specific effects of radiation." These "specific effects" were not enumerated.

It has been shown (*13*) that mice of body weight of 25 gm normally consume about 6 gm of drinking water per day. This is about 24% by weight and represents a higher consumption per unit of weight than that shown by rats, rabbits, guinea pigs, or hamsters. The lowest rate of water consumption is by the albino rat rather than the hamster, as one might assume.

Conclusions

This study was initiated on the presumption that it would help to spot those organs or tissues that showed the greatest shift in water balance so that further studies could be focused on those particular organs with the hope of maintaining their specific water content and thereby "protect" the animal.

As often happens in research, the results are diametrically opposed to those anticipated. The water shift (percentage wise) seems to be secondary to an almost universal decrease in dry (material) weight of the various tissues studied. True, the adrenal gland showed an increase in water percentage (13 and 12%), but this type of change can follow stress situations (*14–17*); the same adrenal showed an absolute decrease in dry weight by 38% and 40% in the two sets of experiments. Likewise, muscle, bone, and carcass exhibited an actual increase in water percentage following a lethal exposure to X-irradiations, while the brain (in addition to muscle, bone, and carcass) showed an increase in dry weight. This was, indeed, the most startling aspect of this study, for the nervous tissues of the adult have long been regarded as highly radioresistant. The 15 mice X-irradiated in the two series showed increase of 4 and 14.3% in dry weight of the brain over the 15 comparable controls. Very possibly we will be obliged to return to the nervous system as the more seriously, though less obviously, affected of all the systems by sublethal and lethal exposure to ionizing radiations.

The dry weight showed the maximum relative decrease in thymus, spleen, and adrenal, as one might expect from general cytopenia. However, when one considers the entire aggregate of tissues, there was a decrease of 5.6% and 18.3% in dry weight. This was quite different from the percentage change in water, which actually showed an increase when the aggregate of tissues was considered. It is certainly suggestive that X-radiation damage involves the solid materials of protoplasm more drastically than the fluid balance, although one cannot deny the latter and its possible causal relation to the former.

* * *

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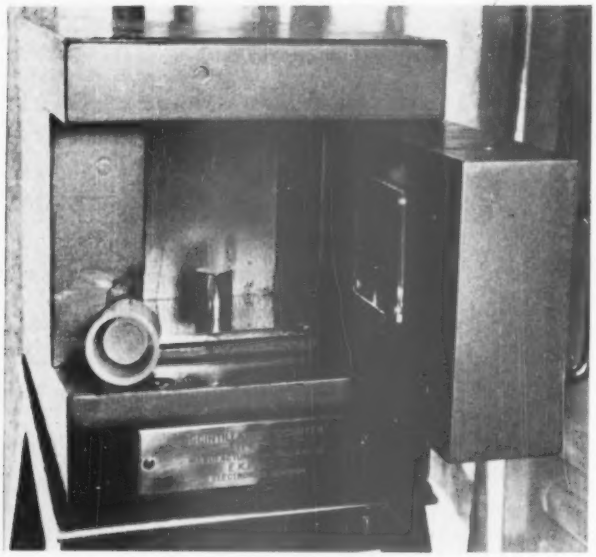
Gamma-Ray Scintillation Counter for Weak Radioactive Solutions



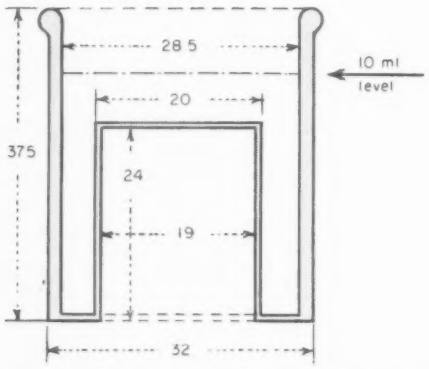


FIG. 1. Scintillation counter arrangement. Sample container, lying on one side at left, is diagramed at right (dimensions in mm)

By C. P. HAIGH
Research Department
Barrow Hospital, Barrow Gurney
Bristol, England

MANY RADIOACTIVE TRACER investigations, especially in medical and biological work where the size of the dose is restricted, involve measuring radioactive samples of very low activity. Frequently, the most sensitive technique is to use liquid samples with a dipping or jacketed thin-walled beta counter. If the assay can be made by gamma as well as by beta counting, the scintillation counter, with its very great gamma-ray detection efficiency, may be used often with considerable advantage, provided the optimum conditions for measuring weak samples are established.

This paper concerns a gamma-ray scintillation counter adapted to take liquid samples of up to 10 ml, and a comparison of its performance with that of the jacketed beta counter for measuring solutions of I^{131} (γ:86% 0.637, 14% 0.363, 0.282, 0.08 Mev) and Fe^{59} (γ:50% 1.3, 50% 1.1 Mev).

In Britain, the jacketed beta counter (*1, 2*) has become almost a standard instrument for this purpose, although its efficiency falls rapidly with beta-ray energy, and it is completely insensitive to beta rays below 0.3 Mev. Thus, while for isotopes such as P^{32} (β:1.7 Mev) and Na^{24} (β:1.4 Mev) sensitivities (defined as counting rate/sample disintegration rate) approaching 10% can be obtained, there are several others of importance, notably I^{131} (β:0.60, 0.31 Mev), Fe^{59} (β:0.46, 0.26 Mev), Br^{82} (β:0.45, 0.32 Mev), and Co^{60} (β:0.30 Mev), for which the sensitivity is less than 1%. With I^{131}, for example, the sensitivity is such that about 10^{-9} c (i.e., 10 ml of a solution containing 10^{-10} c/ml) is needed to double the normal background rate of 0.16 to 0.20 cps. This is not the least detectable activity, but under these conditions a minimum combined counting time (*3*) of over 3,000 sec is required to realize an r.m.s. error not greater than 10% (four and ten times this for errors of 5% and 1%, respectively); apart from the uneconomic time factor, large, unknown errors may result from instrument fluctuations during such prolonged measurements. For such isotopes, the jacketed counter, like a number of other liquid-sample counters (*4*), is therefore reaching its useful lower limit at the 10^{-9} c level.

Optimum Operating Conditions

For samples of sufficiently low activity, the sample counting rate, R_s, is of the same order as the background counting rate, R_b. In these circumstances, the magnitude of the counter signal/noise ratio, R_s/R_b, is as important as the sensitivity, $\epsilon = R_s/S$ (where S is the disintegration rate of the sample), in determining the overall merit of the counter. R_s cannot be measured directly but only from separate measurements of $R_t = (R_s + R_b)$ and R_b; it is therefore convenient to use the factor $r = R_t/R_b$ as a measure of signal/noise.

Loevinger and Berman (*3*) have shown that for given values of r and V_s (the required per cent error in R_s) there are certain values of the total, N_t, and background, N_b, counts observed in measuring R_t and R_b that

A scintillation counter provides a practical limit of 10^{-11} c/ml with I^{131} and Fe^{59} solutions, bettering the jacketed beta counter's 10^{-10} c/ml limit. The former is 11–20 times faster for $<10^{-9}$ c/ml

minimize the combined measuring time, $T = T_t + T_b$. These are

$$N_b = \left(\frac{100}{V_s}\right)^2 \frac{\sqrt{r} + 1}{(r-1)^2} \quad (1)$$

$$N_t = N_b r^{3/2} \quad (2)$$

from which

$$T_{\min} = \left(\frac{100}{V_s}\right)^2 \Big/ R_b(\sqrt{r} - 1)^2 \quad (3)$$

In comparing different radiation detectors, or the performance of the same detector under alternative operating conditions, this concept of minimum combined time affords possibly the most useful criterion of over-all efficiency, the best counter or set of operating conditions being that offering the least combined time for measuring a given sample to a given precision. It may thus be shown (*3*) that the merit of a counter is determined by two factors: the sensitivity, ϵ, and the quantity ϵ^2/R_b. The counter having both the largest ϵ and ϵ^2/R_b is always superior to the others and, if having the largest ϵ but not the largest ϵ^2/R_b, is advantageous only for samples of greater than a certain activity.

It follows that, for a particular counter, the operating conditions that are advantageous for all sample strengths are those giving the maximum value of ϵ^2/R_b or, what in practice amounts to the same thing, R_s^2/R_b, where R_s is due to a standard sample of any convenient strength. This advantage is greatest when measuring samples giving R_s nearly equal to zero. For stronger samples the performance may be improved, in theory, by increasing ϵ (thereby reducing ϵ^2/R_b), if this is possible, to values appropriate to the sample strength.

When there is no prior knowledge of the sample strength, the counter is best operated at the point of maximum ϵ^2/R_b. This condition was adopted in the present work. More specialized adjustments for particular sample strengths are mentioned later, although they are rather tedious and in practice do not always yield substantial gains.

Although the foregoing concept provides a means of establishing the optimum signal/noise ratio of the counter, it does not take into account the stability of the instruments, which is especially of importance during extended measurements. A compromise may be needed between the optimum conditions for signal/noise and for stability if the former result in undue sensitivity to fluctuations in the operating voltages.

The preceding analysis is of greater importance in its application to the scintillation counter than to the Geiger tube, since the ϵ and ϵ^2/R_b values of the latter do not change greatly over the allowed range of operating potential, E_g. With the scintillation counter, however, there are several variables that profoundly affect the performance, particularly those that control, at low sample counting rates, the contribution to the background from the relatively large inherent "noise" of the phototube. These variables are of two kinds: (1) those that are under the control of the operator, such as the photomultiplier dynode potentials, E_m (which greatly influence both the sensitivity and background of the instrument), the gain, G, of the amplifier following the multiplier, and the pulse discrimination voltage, E_d; (2) those established in the design of the instrument, apart from the characteristics of the phototube, that determine the signal strength at the photocathode, e.g., the optical coupling between the phosphor and the photocathode and the conversion efficiency of the phosphor. The latter is a function of the energy spectrum of the incident radiation; the conditions realizing the maximum value of ϵ^2/R_b are therefore not the same and must be assessed separately for different radioisotopes.

For a given instrument, the variables E_m, E_d, and, to a smaller extent, G determine the quantity ϵ^2/R_b. There are alternative methods of finding their optimum values. Perhaps the most satisfactory is to measure R_s^2/R_b for some standard source as a function of E_d and for various dynode voltages within the permitted range, and from this family of curves to find the combination (E_m, E_d) giving the maximum value of R_s^2/R_b. With respect to the signal/noise ratio, this is the most advantageous operating point for the radiation concerned. The effect of changing the amplifier gain is to displace the curves along the E_d axis. In practice, it is sufficient initially to fix G at some value, found by trial, that is suitable for the available range of discriminator voltages.

Apparatus

The scintillation counter was a standard commercial model* using an EMI 5311 eleven-stage multiplier tube and incorporating a "ring-of-three" amplifier with preset gains of 30, 100 and 300, the over-all resolving time of the instrument being better than 10^{-7} sec. The phototube and sample chamber were screened by lead of 5 cm minimum thickness. For use with liquid samples the instrument was inverted so that the multiplier tube and amplifier were below and the phosphor projected upwards into the measuring chamber (Fig. 1). The phosphor was a cylindrical crystal of sodium iodide activated with 1% thallium iodide, 23.8 mm long by 17.5 mm diameter and sealed in a thin-walled (0.43 mm) brass container. The liquid samples were placed in cylindrical polythene containers of annular cross-section, which were a sliding fit over the crystal container, thereby surrounding all but the circular base of the crystal with the sample. This arrangement and the dimensions of the sample containers (Fig. 1) were found after many trials to be the best for 10-ml samples (*5*).

The jacketed beta counter was of the most recent type with an evapo-

* The laboratory scintillation counter type N502 manufactured by E. K. Cole Ltd., Southend-on-Sea, England, and modified by them as described in the text.

rated metal cathode.* For low-beta ray energies, the sensitivity of these counters differs considerably from one to another (*2*). A batch of counters, all with similar backgrounds, was examined with both I^{131} and Fe^{59} solutions, and the most sensitive one was chosen. By comparison with the results of Rose and Emery (*2*), it appears that the sensitivity of this counter was near the maximum attainable. It was used in conjunction with a standard lead screen (*1*) and a quenching preamplifier (*6*) with a paralysis time of 200 μsec.

The remaining electronic equipment comprised: a combined pulse discriminator and scaler with an input resolving time of 1 μsec, 5–50 volts variable bias, and a scaling factor of 100; a high-voltage unit with a stability better than 0.1%, output infinitely variable from 0 to 2,000 volts; and a timing unit for measuring preset counts.

Radioactive Standards

The various sources of I^{131} and Fe^{59} were prepared from concentrated solutions containing 1 mc of I^{131} and 5 μc of Fe^{59}, respectively, supplied and measured by the British Atomic Energy Research Establishment. The error in these measurements was said to be not greater than ±5%.

Grade B volumetric apparatus was used for the dilutions. The sources were all aqueous solutions of very nearly unit density, the I^{131} preparations containing 1% sodium iodide and the Fe^{59} preparations 5% ferric chloride and 1% hydrochloric acid for stabilizing purposes. For each radioelement, standards of 1×10^{-10}, 3×10^{-10}, 1×10^{-9}, 3×10^{-9}, 1×10^{-8}, 3×10^{-8}, and 1×10^{-7} c/ml were prepared, the estimated error in any one of these absolute values being no greater than ±6% and that in their ratios (of the same element) no greater than ±2%.

Signal/Noise Ratio

To give high counting rates and hence rapid measurements at each point, 10-ml samples of 10^{-7} c total activity were used for measuring the R_s^2/R_b characteristics of the counters. The sample counting rates were determined to ±1%, and corrections were applied for the 200-μsec resolving time of the beta counter. The R_b characteristics were measured with 10-ml samples of distilled water in the containers, and usually 1,000 counts were recorded at each point (r.m.s. error ±3%) and not less than 400 counts (r.m.s. error ±5%) for the lowest background levels.

The various R_b and R_s values thus obtained were smoothed graphically and values taken from the curves used to calculate the function R_s^2/R_b. In this way, the precision was improved to some extent, it being estimated that the resulting R_s^2/R_b values were subject to errors not greater than ±3%.

The final results are shown in Figs. 2 and 3. With the beta counter, as was expected, both I^{131} and Fe^{59} gave $(R_s^2/R_b)f(E_g)$ curves of similar form and only that for Fe^{59} is shown (Fig. 2). The maximum value of R_s^2/R_b, and hence the optimum working condition, obtained over a considerable range of operating voltage, E_g. In these circumstances, it is an advantage to choose E_g at the point within the possible range where the sensitivity changes least with E_g, although even this is not critical with a good Geiger tube. In the present case, the best operating point was chosen as E_g = 1,100 volts, at which the background was 0.17 cps and the sensitivity changed 0.025% per volt change in E_g.

With the scintillation counter, the amplifier gain was fixed at ×100 and the characteristic $(R_s^2/R_b)f(E_d)$ measured for a range of values of total dynode voltage, E_m, increased in 50-volt steps. The curves due to I^{131} and to Fe^{59} were not of the same shape (Fig. 3). There are several conclusions to be drawn from the results:

1. For the various values of E_m within the range of interest, the corresponding R_s^2/R_b maxima are fairly sharply defined with respect to the discrimination voltage, E_d, apparently more particularly with lower energy gamma rays. The scintillation counter is therefore more sensitive to maladjustment than the Geiger tube.

2. For E_m values within a fairly wide range, values of E_d can be found resulting in R_s^2/R_b values nearly equal to the maximum attainable. In the case of I^{131}, for example, the operating conditions defined by (E_m, E_d) values of (1,400, 17.5), (1,450, 22.5), (1,500, 25) and (1,550, 30) volts give minimum combined times for measuring a given sample to a stated precision all within a few per cent.

Thus, there are a number of pairs of (E_m, E_d) values that effectively provide the most advantageous signal/noise ratio. The best choice is that yielding maximum stability if there is any significant variation in this respect, i.e., the (E_m, E_d) pair for which fluctuations in E_m, E_d and G result in the least change in the sensitivity and background of the counter. This choice may be made with the help of the several curves relating R_s and R_b to E_m and E_d.

Although the present scintillation counter was particularly stable, this question of stability was taken into account in choosing the following operating conditions most advantageous for all sample strengths: I^{131}—E_m = 1,450 volts, E_d = 22.5 volts; G = 100; Fe^{59}—E_m = 1,500 volts, E_d = 27.5 volts, G = 100.

At both these points the background was 0.46 cps, changing about 0.3% and 0.25% per volt change in E_d and E_m, respectively. The change in the sample counting rate was no greater than 1.5% per volt change in E_d in both cases and no greater than 0.15% and 0.11% per volt change in E_m for the I^{131} and Fe^{59} settings, respectively. The reproducibility of the sensitivity was therefore of the order of ±1%.

3. The difference in the optimum conditions for 0.637- and 1.3-Mev gamma radiation is small. To use the optimum setting for I^{131} when working with Fe^{59} results in an R_s^2/R_b value only 5% less than the maximum available for Fe^{59}. Therefore, the optimum adjustment of the scintillation counter was not profoundly influenced by the energy of the gamma rays within this range. Nevertheless, the tendency appears to be for the optimum operating point to move to greater values of both E_m and E_d with increasing gamma-ray energy. This is not unexpected since the intensity of the scintillations increases with gamma-ray energy, resulting in a greater signal/noise ratio at the photocathode and thus making possible greater multiplication factors for a given final signal/noise ratio.

Sensitivity vs Sample Volume

With I^{131} and Fe^{59} solutions of 10^{-8} c/ml, the counting rates of both instruments were measured as a function of sample volumes.

* Known as the CV2145, or the type M6 manufactured by Twentieth Century Electronics, Dunbar Street, London, S.E.27, England.

The results given in Fig. 4 are conveniently expressed in terms of the quantity $Q = (R_v/v)/(R_{10}/10)$, where R_v and R_{10} are the counting rates due to samples of v and 10 ml, respectively. These $Qf(v)$ curves are independent of the sample strength.

For each counter there was an optimum sample volume giving maximum sensitivity—5.5 ml for the beta counter and 3 to 4 ml with the scintillation counter. The latter had a sensitivity less dependent on the sample volume than that of the beta counter, and it had the same $Qf(v)$ characteristic for both the isotopes examined.

The relative increase in sensitivity with the optimum sample volumes over that with the 10 ml samples was 1.48 and 1.59 for Fe^{59} and I^{131}, respectively, with the beta counter and 1.27 in both cases with the scintillation counter. With the beta counter, this effect is due mainly to variations in wall thickness, particularly at the ends of the tube. Imperfect optical properties and nonuniformity of the phosphor are principally responsible in the case of the scintillation counter, geometrical changes probably contributing also for sample volumes approaching 10 ml.

In relation to the over-all efficiency of liquid counters, two principal types of measurements must therefore be considered: (a) measurement of the specific activity of solutions for which the greatest sensitivity obtains with the maximum sample volumes; (b) measurement of a given total activity, the greatest sensitivity resulting when the sample is concentrated in the optimum liquid volume for the particular counter.

Specific activity measurements are possibly the more common. Since, in any case where the sample activity is sufficiently great, it is preferable to work with constant sample volumes, the majority of measurements are of the first type. For very weak radioactive samples, however, it is advantageous to work with optimum sample volumes, assuming this is possible. This may result in rather more elaborate experimental techniques and the introduction of correction factors, but there is a useful gain in sensitivity at very low levels of activity.

Sensitivity Measurements

The sensitivities of the two counters, each working under the most advantageous conditions for the isotope concerned, were measured using the range of I^{131} and Fe^{59} solutions previously mentioned. The measurements were made with 10-ml samples, and the results relating to the optimum sample volumes were calculated by means of the various sensitivity factors given above.

The counting rates due to each standard solution were determined to a statistical error of $\pm 1\%$ (except for the 10^{-10} c/ml standards in the beta counter). Within this error the sensitivities were found to be constant over the given range of sample strengths.

The results, shown in the table, are the means of the various groups of measurements. The sensitivities, e = sample counting rate/sample disintegration rate, are expressed as percentages and also in terms of the counting rates (per sec) due to samples of 10^{-9} c total activity. The errors in the absolute sensitivities include those in the radioactive standards to which the sensitivity ratios are not subject.

The background of the beta counter

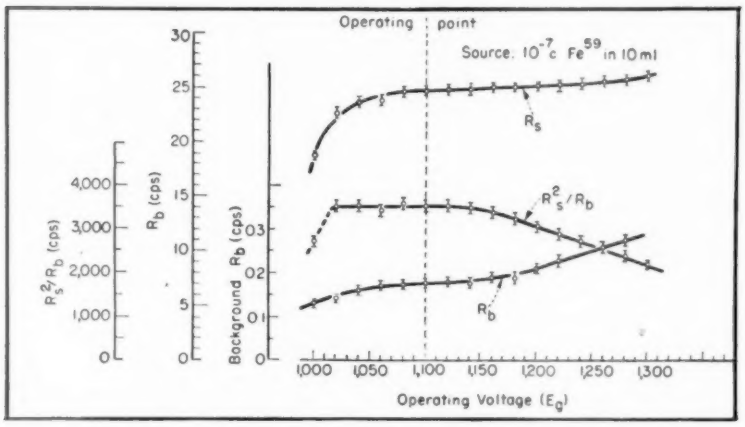


FIG. 2. Characteristics of beta counter with Fe^{59}; similar results obtained with I^{131}

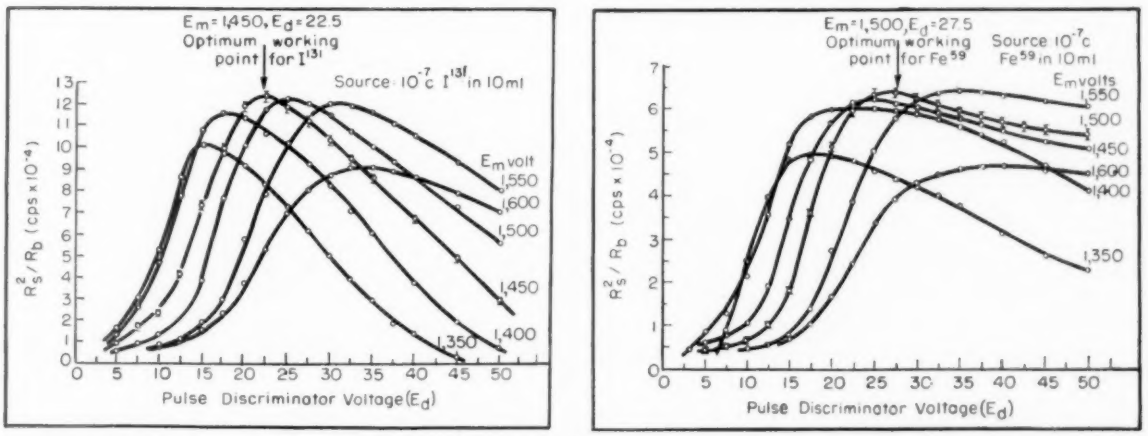


FIG. 3. Signal/noise characteristics of scintillation counter (to avoid confusion, errors indicated on only one curve)

Comparison of Sensitivities of Gamma-Ray Scintillation and Beta Counters

		Gamma-ray scintillation counter					*Jacketed beta counter*						
Measuring technique	*Isotope*	*Sample volume (ml)*	*Efficiency, e_1*	*Counting rate due to 10^{-9} c sample (cps)*	*Sample giving $R_s = R_b$ (curie)*	*Bkgd., R_{b_1} (cps)*	*Sample volume (ml)*	*Efficiency, e_2*	*Counting rate due to 10^{-9} c sample (cps)*	*Sample giving $R_s = R_b$ (curie)*	*Bkgd., R_{b_2} (cps)*	e_1/e_2	R_{b_1}/R_{b_2}
Specific activity measurement	I^{131}	10	6.1 ± 0.37	2.26 ± 0.14	2.04 × 10^{-10}	0.46	10	0.70 ±0.042	0.26 ± 0.015	6.5 × 10^{-10}	0.17	8.7 ± 0.12	2.7
	Fe^{59}	10	4.4 ± 0.26	1.63 ± 0.1	2.8 × 10^{-10}	0.46	10	0.46 ± 0.028	0.17 ± 0.01	1 × 10^{-9}	0.17	9.6 ± 0.13	2.7
Optimum liquid volume method	I^{131}	3.5	7.75 ± 0.47	2.87 ± 0.17	1.6 × 10^{-10}	0.46	5.5	1.1 ± 0.067	0.41 ± 0.025	4.6 × 10^{-10}	0.19	7.0 ± 0.1	2.4
	Fe^{59}	3.5	5.6 ± 0.34	2.07 ± 0.12	2.2 × 10^{-10}	0.46	5.5	0.68 ± 0.041	0.25 ± 0.015	7.6 × 10^{-10}	0.19	8.2 ± 0.12	2.4

depended on the sample volume and was slightly greater with the 5.5 ml optimum volume than when the jacket was full. This tends to offset the advantage of using optimum sample volumes at low activity levels.

Discussion

Depending upon the particular measuring technique employed, the gamma-ray scintillation counter described here is between 7 and 9.6 times more sensitive than the Veall beta counter for assaying liquid samples of I^{131} and Fe^{59}, the greatest increases being for the more useful specific activity measurements with 10-ml samples. For strong samples giving $R_s \gg R_b$, these factors are a direct measure of the superiority of the γ-ray method.

The background rate, R_b, of the scintillation counter is not greater than 2.7 times that of the beta counter. Thus, the former instrument has not only the larger sensitivity, e, but also the larger e^2/R_b value and is therefore always the better instrument for measuring I^{131} and Fe^{59} solutions, whatever the concentration. Moreover, the gain becomes progressively greater with decreasing sample strengths.

Consider initially the sample strengths given in the table resulting in sample counting rates equal to the background rate, $R_s = R_b$, for the two instruments and different measuring techniques. This condition is in fairly general use as an indication of the minimum measurable sample activity. The results suggest that, in general, the scintillation counter is useful for samples of 0.25 to 0.3 times the least activity measurable with the beta counter. On this $R_s = R_b$ basis, and for I^{131}, both these counters are apparently superior to any of the several liquid counting methods reviewed by Bruner and Perkinson (*4*), the scintillation counter by a factor not less than 6.

Counting time. The $R_s = R_b$ criterion is not a complete indication of the weak-sample performance of counters for it is principally concerned with their signal/noise ratio and does not take into account the time required for the measurements. For this purpose, the more satisfactory minimum-combined-time criterion must be used.

The minimum combined time required by each counter to measure I^{131} and Fe^{59} samples within an r.m.s error of ±10% has been calculated from Eq. 3 and is plotted as a function of sample strength in Fig. 5. For simplicity, these curves relate only to the use of 10-ml samples, the so-called specific activity measurements. They may be used for any other per cent error, V_s, by multiplying the 10% error time scale by the factor $(10/V_s)^2$.

In the case of the scintillation counter, the curves for the more sensitive optimum sample volume condition may be derived by dividing the ordinate of Fig. 5 by the relative sensitivity factor 1.27. This procedure is only approximate, especially for the weaker samples, in the beta-counter case owing to the change in background with sample volume.

The minimum-combined-time curves summarize the performances of the counters and only a few comments are needed. For measuring to a given precision samples of total activity 10^{-8} c (i.e., solutions of 10^{-9} c/ml), the scintillation counter is 11.0 and 13.0 times more rapid than the beta counter for I^{131} and Fe^{59}, respectively. At 10^{-9} c total activity, these factors increase to 15.5 and 20.0, and to 24.0 and 30.0 at the 10^{-10} level.

Actually, it is doubtful if the beta counter would be used for samples below 10^{-9} c, for at this level the minimum combined time to realize an error of 10% is already of the order of 2,000 sec. In a similar time, the scintillation counter could measure a sample of about 1.7×10^{-10} c to the same precision. Thus, in terms of the measuring time required for samples of below 10^{-8} c, the scintillation counter is better than the beta counter by a factor of 11.0 to 20.0, and it extends the range of measurements by a factor of about 10 below the least activity measurable with the beta counter. This superior time requirement of the scintillation counter is a tremendous advantage in work with many weak samples. Even at the lowest measurable activity levels (solutions of $\sim 10^{-11}$ c/ml), the instrument's high stability gives confidence in the results of lengthy measurements.

Other radioisotopes. This improved performance is not confined to I^{131} and Fe^{59}, but obtains for any radioisotopes having a favorable relation between the beta and gamma-ray energies. For example, according to

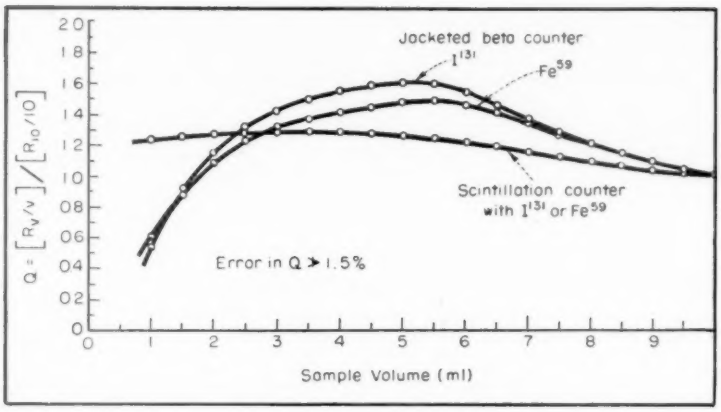


FIG. 4. Effect of sample volume on counter sensitivity

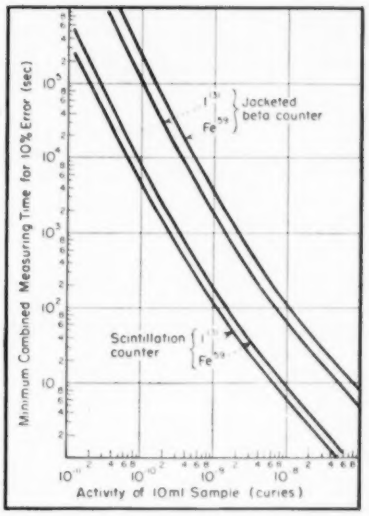

Minimum Combined Measuring Time for 10% Error (sec)
Jacketed beta counter
Scintillation counter
Activity of 10ml Sample (curies)

FIG. 5. Minimum-combined-time requirements for assaying I^{131} and Fe^{59} solutions within a 10% error

Rose and Emery (*2*) the sensitivity of the Veall counter for 10-ml solutions of Br^{82} and Co^{60} is at most 0.53 and 0.70, respectively, of that for I^{131}. These isotopes emit gamma rays [Br^{82} (γ:1.32, 1.04, 0.77 Mev, etc.), Co^{60} (γ:100% 1.17, 1.33 Mev)] and may therefore be assayed using the scintillation counter with an advantage certainly not less than was found for I^{131} or Fe^{59}. In fact, with Co^{60}, which emits two photons of similar energy per disintegration, the advantage of the scintillation counter may be more than twice that for I^{131} and Fe^{59}, although in any statistical considerations allowance must be made for the proportion of disintegrations producing two counts owing to the high efficiency of the scintillation counter. With Na^{24}, for which the Veall counter sensitivity is more than 10 times that for I^{131}, the scintillation counter offers no advantage apart from its superior resolution time.

Liquid vs dry counting. In general, solid samples can be assayed by beta counting with a greater sensitivity than liquid samples, but the gamma-ray method now provides a routine sensitivity with liquid samples in many cases comparable to that possible with dry beta counting. The present arrangement is almost as good for I^{131} as the gas-flow proportional counter, is for dry samples (*4*).

Given similar detection sensitivities, liquid samples are probably superior to dry samples in most respects since they are better geometrically, are usually more easily prepared and less influenced by small irregularities in preparation, and involve more certain absorption corrections if necessary.

Rose and Emery (*2*) have considered absorption corrections in relation to the Veall beta counter for liquids of different chemical composition and density. In the present work, absorption effects were not investigated, for with gamma counting, especially with energies greater than 0.5 Mev and small volumes of liquids of low density, it seems reasonable to neglect absorption effects unless there are outstanding differences in the standard and unknown solutions.

Voltage settings. It has been mentioned that for the scintillation counter there are operating conditions that are more advantageous at and above particular sample strengths than the standard setting, corresponding to the maximum value of e^2/R_b, which is most advantageous for samples giving R_s nearly equal to zero. To establish these alternative conditions is rather tedious, but to estimate the resulting gain in performance the calculations were made for several levels of sample activity.

For 10-ml I^{131} samples of 10^{-10} c, the best operating point was E_m = 1,450, E_d = 19 volts, which compared with the standard setting gave ~1% saving in the minimum combined measuring time. For samples of 10^{-9} and 10^{-8} c, the optimum (E_m, E_d) settings were (1,400, 15) and (1,550, 21.5) volts, yielding time savings of 3% and 6%, respectively. A similar state of affairs was found with Fe^{59}.

This makes it clear that there is little to be gained, at least with the present instrument, by seeking the best operating conditions for particular sample strengths below 10^{-8} c; above this, the measuring periods are in any case becoming relatively short.

Geometry. Another possibility is to improve the counter-source geometry, for with the present arrangement the phosphor is traversed by rather less than 50% of the gamma rays from the sample.

Apparently the sensitivity could be improved, approximately by a factor of two, if the sample were enclosed by or fitted into a kind of well in the phosphor. However, unless smaller samples were used, with a corresponding reduction in the sensitivity for specific activity measurements, a much larger crystal would be needed resulting in a greater background and inferior light transmission to the photocathode. With these factors in mind substantial gains in performance do not seem likely from improved geometry.

* * *

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Analysis of Radiation Fields of Two Gamma-Radiation Sources

An analysis of the radiation fields of two multikilocurie cobalt-60 gamma sources is presented. A study of the discrepancies between activities based on dosage determinations and those based on reactor computations is included

By JOHN G. LEWIS, JOHN V. NEHEMIAS, DAVID E. HARMER, and JOSEPH J. MARTIN
Fission Products Laboratory, University of Michigan
Ann Arbor, Michigan

IN THE COURSE OF A PROGRAM to ascertain the effects of gamma radiation on a variety of materials, it has been desirable to determine quantitatively the amount of radiation to which the materials are exposed. Chemical and physical dosimetry of the radiation fields of the sources has been compared with dose rate calculations from activities estimated by others from neutron irradiation.

Sources

The two gamma-radiation sources that have been employed both contain cobalt-60 as the active material.

1,000-curie source. The older source is a hollow cylinder of cobalt with an inside diameter of about 2 in., a wall thickness of $\frac{1}{4}$ in., and a length of about 14 in. The cylinder is sealed in a thin aluminum jacket and is stored inside a lead vault that is about 2 ft in diameter and 3 ft high (*1*).

Samples to be irradiated are suspended down the center of the cobalt cylinder. This central region and the region above it constitute the neighborhood of interest for radiation-intensity studies. The cylinder of cobalt-60 was produced in the pile at Brookhaven National Laboratory and nominally rated at 1,000 curies (July, 1951).

10-kc source. The newer source consists of a bundle of 100 cobalt rods, each $\frac{1}{4}$ in. in diameter and 10 in. long. The rods are encapsulated in thin aluminum jackets and are mounted in a circular holder, as shown in Fig. 1, whose inside diameter is about 7 in. When not in use, the holder with its 100 cobalt rods is stored near the bottom of a 17-ft-deep well of water.

For a given radiation experiment, the holder is raised to floor level of the room that is shielded with concrete walls 4 ft thick. The radiation samples may be placed so that they are in the center of the raised holder of rods or are above it or around it. These are the regions of interest for dosimetry measurements with this source.

The 100 cobalt-60 rods were produced in the pile at Chalk River, Ontario, Canada, and were given a nominal rating of 9,250 curies (December, 1952).

Experimental Procedure

Dose rates were measured chemically by the oxidation of ferrous sulfate solutions. Dilute solutions of ferrous sulfate ($5 \times 10^{-4}M$) in aerated $0.8N$ sulfuric acid solution were exposed to gamma radiation for dosgs of between 5 and 20 krep. The ferric ion produced by the gamma radiation depends upon the presence of a small amount of oxygen, which is readily furnished by first passing air through the solution. For quantitative determinations of the ferric ion produced by irradiation, the spectrophotometric method described by J. Weiss of Brookhaven National Laboratory was employed (*2*). This method makes use of a spectral absorption peak of ferric ion at about 304 millimicrons in the ultraviolet region. Optical densities of the irradiated solutions are measured at 305 mμ and compared with those of known ferric solutions made up by dilution of standardized ferric stock solution.

In converting the chemical yield to radiation dosage, a value of 15.4 micromoles/liter/krep was used. This value is based on the absorption of 93 ergs/gm of water for each roentgen of radiation. The solutions were irradiated in glass bottles that were about 3-cm inside diameter and were filled to a depth of about 4 cm.

The bottles of solution were placed inside and outside the 10-kilocurie source, and were placed inside the 1-kc source. Proper exposure times were calculated to fall within the range of the ferric ion determination. Measurement of dose rate in the 1-kc source was carried out at times separated by an interval of 1 year, and values were found to be consistent after corrections for radioactive decay were applied. Measurements using a ceric sulfate system were also made and found to agree within experimental error with the ferrous sulfate results.

Physical determinations. Two instruments were employed in the physical determinations of the dose rates of both sources.

First, a Victoreen roentgen rate meter measured the current flow between electrodes in an ionization chamber placed in the radiation field.

Second, a Victoreen r-meter meas-

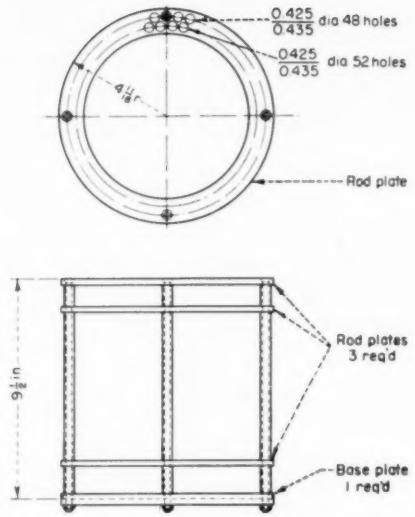

FIG. 1. Rod-holder assembly of 10-kc source

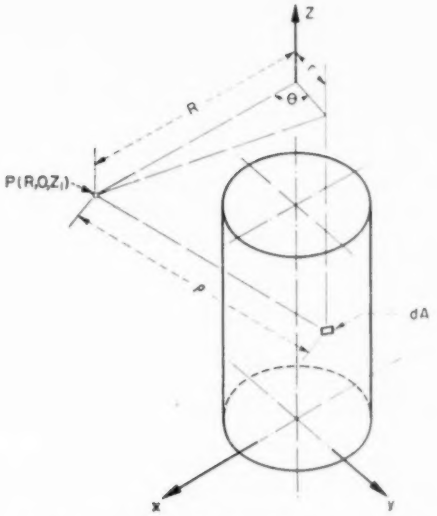

FIG. 2. Geometry of cylindrical source having negligible wall thickness

ured the drop in potential of a charged capacitor due to ionization current caused by the radiation. The rate meter was calibrated against radium standards by the manufacturer, while the r-meter was calibrated against a cobalt standard at the University of Michigan.

Within 50 cm of the center of the 10-kc source, the rate-meter readings were 15–20% lower than the ferrous sulfate determinations. The r-meter readings were 15–20% higher than the ferrous sulfate measurements in the 1-kc source. The detailed significance of these differences is not clear.

Calculation Procedure

Since gamma radiation from a point source may be assumed to follow the usual inverse-square relation, it is possible to calculate the dose rate at any position in the neighborhood of a source of known shape and total activity by an integration technique similar to that employed in radiant-heat transfer. If the geometry of the source shape is complicated, the resulting integration may be difficult.

As a simple shape somewhat similar to the two cobalt-60 sources, one may first consider a hollow cylinder of negligible wall thickness and assign to it the power or curie rating of the actual source (Fig. 2). The dimensions of the cylinder are taken to correspond as nearly as possible to those of the actual source, and the assigned curies are assumed to be distributed uniformly over the surface of the cylinder. Then the contribution to the radiation intensity at any given point due to an element of source area dA, at a distance ρ away, is given by

$$dI = \alpha\, dA/\rho^2 \tag{1}$$

The total intensity at the given point is obtained by summing the contributions from all elemental areas as

$$I = \int_{Z=0}^{Z=L} 2 \int_{\theta=0}^{\theta=\pi} \frac{\alpha r d\theta\, dZ}{R^2 + r^2 - 2Rr\cos\theta + (Z_1 - Z)^2} \tag{2}$$

Integrating Eq. 2

$$I = \frac{2\alpha\pi r}{R+r}\left[F\left(\tan^{-1}\frac{R+r}{Z_1 - L}, k\right) - F\left(\tan^{-1}\frac{R+r}{Z_1}, k\right)\right] \tag{3}$$

for $Z_1 > L > 0$, $R \geq 0$, $r > 0$,

$$0 \leq \tan^{-1}\frac{R+r}{Z_1 - L}, \tan^{-1}\frac{R+r}{Z_1} < \frac{\pi}{2}$$

and,

$$I = \frac{2\alpha\pi r}{R+r}\left\{2K(k) - \left[F\left(\tan^{-1}\frac{R+r}{L - Z_1}, k\right) + F\left(\tan^{-1}\frac{R+r}{Z_1}, k\right)\right]\right\} \tag{4}$$

for $L \geq Z_1 \geq 0$, $R \geq 0$, $r > 0$, $R \neq r$,

$$0 \leq \tan^{-1}\frac{R+r}{L - Z_1}, \tan^{-1}\frac{R+r}{Z_1} \leq \frac{\pi}{2}$$

An alternative form may be obtained as shown by Eq. 5. Dewes and Goodale (3) have indicated the preliminary steps in this development

$$I = \frac{2\alpha\pi r}{R+r}\left[F\left(\tan^{-1}\frac{Z_1}{|r-R|}, k\right) - F\left(\tan^{-1}\frac{Z_1 - L}{|r-R|}, k\right)\right]$$

for $Z_1 \geq 0$, $R \geq 0$, $r > 0$, $R \neq r$,

$$-\frac{\pi}{2} < \tan^{-1}\frac{Z_1 - L}{|r-R|} < \frac{\pi}{2},$$

$$0 \leq \tan^{-1} Z_1/|r-R| < \frac{\pi}{2} \tag{5}$$

A relation given by Hancock (4) permits the transformation of Eqs. 3 and 4 into Eq. 5, and vice versa. Equation 5 is considered more convenient in most computations, except for $R = r$, $Z_1 > L$, where Eq. 3 may be used.

The symbols used are defined as:

I = dose rate, equivalent roentgens per hour
A = area of source
ρ = distance from elemental area dA to the point at which I is taken
α = (total activity, curies/area of source, cm²)(1000 mc/curie)(equiv. roentgens at 1 cm./hour × millicurie point source)
r = radius of source; also constant radius vector of cylinder
R = radial distance of point at which I is taken from axis of source
θ = central angle from R to r
Z = distance parallel to axis of source from base of source to element dA
Z_1 = Z coordinate of point at which I is taken

$k = 2\sqrt{Rr}/(R + r)$

$F(\phi,k)$ = elliptic integral of first kind of modulus k and amplitude ϕ

$K(k)$ = complete elliptic integral of first kind of modulus k

Self-absorption. Self-absorption of a hollow cylindrical source of finite thickness may be approximated along the axis of the source by the following procedure (see Fig. 3).

It is assumed (1) that the source is of uniform unit-volume activity and density, (2) that absorption occurs only within the source, (3) that scattered radiation due to the absorber does not affect the dose rate, (4) that radiation intensity and dose rate vary inversely with the square of the distance from a point source and inversely with an exponential function of absorber thickness, and (5) that the part of the source lying outside the cone $\phi = \tan^{-1} r_1/(Z_1 - L)$ also fulfills the foregoing assumptions.

The resulting differential equation and its approximate integration are

$$dI = V(dv/P^2)e^{-\mu P'\rho} \qquad (6)$$

$$I = \int_{r=r_1}^{r=r_2}\int_{Z=0}^{Z=L}\int_{\theta=0}^{\theta=2\pi} V\frac{rd\theta dZdr}{r^2 + (Z_1 - Z)^2}e^{-\mu\rho(r-r_1)\sec\phi} \qquad (7)$$

If a three-term approximation to the exponential is employed

$$\begin{aligned} I = {} & 2\pi V\left\{r_2\left[\tan^{-1}\frac{Z_1}{r_2} - \tan^{-1}\frac{Z_1 - L}{r_2}\right]\right. \\ & - r_1\left[\tan^{-1}\frac{Z_1}{r_1} - \tan^{-1}\frac{Z_1 - L}{r_1}\right] \\ & + \frac{Z_1 - L}{2}\ln\frac{1 + [r_1/(Z_1 - L)]^2}{1 + [r_2/(Z_1 - L)]^2} \\ & \left. + \frac{Z_1}{2}\ln\frac{1 + [r_2/Z_1]^2}{1 + [r_1/Z_1]^2}\right\} \\ & + 2\pi V\mu\rho\left\{\left[\frac{r_2^2}{2} - r_2r_1\right]\right. \\ & \left[\sinh^{-1}\frac{Z_1 - L}{r_2} - \sinh^{-1}\frac{Z_1}{r_2}\right] \\ & + \frac{r_1^2}{2}\left[\sinh^{-1}\frac{Z_1 - L}{r_1} - \sinh^{-1}\frac{Z_1}{r_1}\right] \\ & + \left[\frac{Z_1 - L}{2}\right]\left[r_2\sqrt{\left(\frac{Z_1 - L}{r_2}\right)^2 + 1}\right. \\ & \left.\left. - r_1\sqrt{\left(\frac{Z_1 - L}{r_1}\right)^2 + 1}\right] \\ & - Z_1/2\left[r_2\sqrt{(Z_1/r_2)^2 + 1}\right. \\ & \left. - r_1\sqrt{(Z_1/r_1)^2 + 1}\right] \\ & + [Z_1 - L]r_1\ln \\ & \frac{r_1}{r_2}\left[\frac{\sqrt{\left(\frac{Z_1 - L}{r_1}\right)^2 + 1} + 1}{\sqrt{\left(\frac{Z_1 - L}{r_2}\right)^2 + 1} + 1}\right] \\ & \left. - Z_1r_1\ln\frac{r_1}{r_2}\left[\frac{\sqrt{\left(\frac{Z_1}{r_1}\right)^2 + 1} + 1}{\sqrt{\left(\frac{Z_1}{r_2}\right)^2 + 1} + 1}\right]\right\} \\ & + \pi V\mu^2\rho^2L\{[r_2^2 - r_1^2]/2 \\ & - 2r_1[r_2 - r_1] + r_1^2\ln r_2/r_1\} - \ldots \end{aligned} \qquad (8)$$

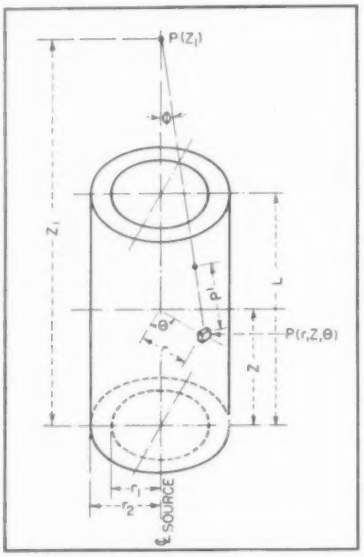

FIG. 3. Geometry of cylindrical source of finite wall thickness

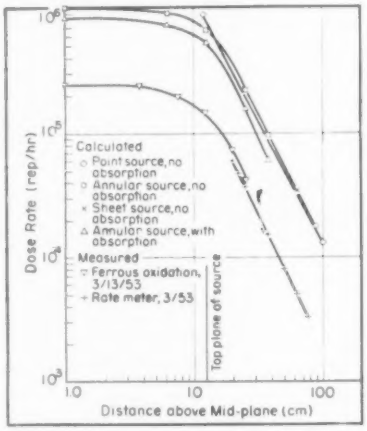

FIG. 4. Dose rate on axis of 10-kc Co^{60} source

for $Z_1 \geq 0$, $-\pi/2 < \tan^{-1}(Z_1 - L)/r_1$, $\tan^{-1}(Z_1 - L)/r_2 < \pi/2$;

$0 \leq \tan^{-1} Z_1/r_1$, $\tan^{-1} Z_1/r_2 < \pi/2$;

$r_1 > 0$, $r_2 > 0$, $r_1 \neq r_2$

where P = distance between point and element of volume, ρ = density (gm/cm³), μ = mass absorption coefficient (cm²/gm), V = (total activity, curies/volume of source, cm³)(1,000 mc/curie)(equiv. roentgens at 1 cm/hour × millicurie point source), and dv = element of volume of source.

All other terms are defined as previously or in Fig. 3.

Equations 5 and 8 were applied to both the 1,000- and 10,000-curie sources. In the case of the 1,000-curie source, it was simple to assume a cylinder with dimensions corresponding to the actual cobalt cylinder.

In the case of the 10,000-curie source, the nest or bundle of 100 rods was assumed equivalent to a cylinder whose inside and outside diameters were the shortest and longest diametrical distances across the rod bundle. The 10,000 curies was assumed to be uniformly divided throughout this volume, and the density of the assumed cylinder was taken so that its mass equalled that of the rods themselves.

Dose rate of 10-kc source. Calculated and observed values of dose rate for the 10-kc source of cobalt-60 are plotted in Figs. 4 and 5.

The calculated values were based on an assumed activity of 10,000 curies. The observed values are considerably less than the calculated values. For any given method of measurement, the observed values are a nearly constant fraction of the calculated values.

The activity computed from each means of measurement appears in the table. In the extreme right column of the table, there appears the ratio of the curies estimated from observed values of dose rate to the 9,250-curie nominal value after correction of the latter value for decay.

If self-absorption is not considered, the activity is estimated to be from 17 to 33% of the nominal value. If self-absorption is considered, the activity is estimated to be from 28 to 33% of the nominal value. These figures are computed from data taken both on the midplane and on the axis. No estimate of self-absorption was made on the mid-plane, however.

Dose rate of 1-kc source. Calculated and observed values of dose rate

Estimates of Activities from Measurements of Dose Rates

Measurements			*Estimate of activity (curies)*			*Mean value divided by decayed nominal value*
Where taken	*Method*	*Date*	*Maximum*	*Minimum*	*Arithmetic mean*	
0-kc source						
Axis	Ferrous oxidation	3/53	2,500	2,100	2,300	0.26
			3,100*	2,800*	2,950*	0.33*
	Victoreen Rate Meter	3/53	1,700	1,400	1,550	0.17
			2,600*	2,500*	2,550*	0.28*
Mid-plane	Ferrous oxidation	3/53	2,600	2,200	2,400	0.27
	Victoreen Rate Meter	3/53	2,500	2,000	2,250	0.25
	Victoreen r-meter	3/53	3,000	2,900	2,950	0.33
1-kc source						
Axis	Ferrous oxidation	5/52			140	0.16
					180*	0.20*
		5/53			130	0.16
					170*	0.21*
	Victoreen Rate Meter	2/53	150	110	130	0.16
			190*	150*	170*	0.20*
	Victoreen r-meter	5/52			170	0.19
					230*	0.26*
		5/53			160	0.20
					210*	0.26*

* Estimates for which self-absorption was considered.

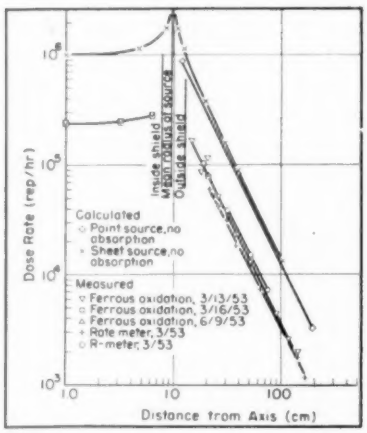

FIG. 5. Dose rate on midplane of 10-kc Co^{60} source

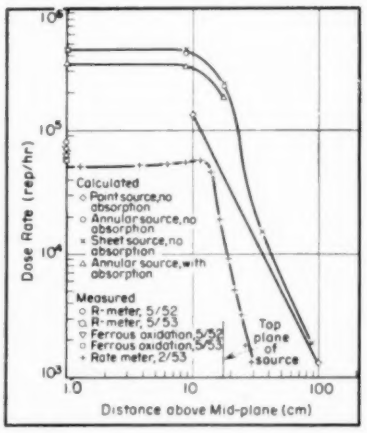

FIG. 6. Dose rate on axis of 1-kc Co^{60} source

and curies for the 1-kc source are compared in Fig. 6.

The activity computed from each means of measurement is given in the table. The ratios of observed-to-decayed nominal curies appear in the right column. If self-absorption is not considered, the activity is estimated to be from 16 to 20% of the nominal value. If self-absorption is considered, the activity is estimated to be from 20 to 26% of the nominal value. The figures are computed from data taken on the axis only.

Judging from the above results, there appears a discrepancy of about three-fold between the curies in the 10-kc source, as estimated from ionization measurements and as calculated from neutron absorption. The comparisons for the 1-kc source are not so meaningful, since no firm estimate of the activity of the source was supplied by the makers.

Errors in calculation. The errors in the methods of calculation summarized in Eqs. 3, 5, and 8 probably arise chiefly from the assumptions made.

The assumption that the source has no thickness is evidently justified by the agreement of values calculated on this assumption with those in which thickness of the source is considered (see Figs. 4 and 6). However, in Figs. 4 and 5 it can be seen that the plots from data and from Eqs. 3, 5, and 8 differ by an approximately constant factor between any pair of curves. This result is interpreted to mean that Eqs. 3 and 5 may be used within limits to predict the distribution of dose rates without consideration of self-absorption, but that accurate prediction of dose rates requires consideration of self-absorption.

Figure 6 indicates that the 1-kc source is not of uniform activity throughout its whole volume. The measured dose rates in the 1-kc source do not vary with distance along the axis in the manner predicted by the calculated curves. The depression near the mid-plane is probably caused by lower unit activity inside the source in this region. The lower unit activity here is probably caused by failure of neutrons to penetrate to the interior of the source near the midplane as abundantly as near the ends.

The other assumptions introduced are thought to be reasonably acceptable, although Eq. 8 converges much more slowly as Z_1 is increased. The value of 13.5 rep/hr at 1 cm per millicurie point source of cobalt-60 was taken from the work of Marinelli, Quimby, and Hine (*5*), and was assumed to be correct to within our experimental error.

Neutron-absorption activity calculation. Differences between the chemical and physical dosimetry measurements were not sufficiently large to account for the factor of three or four between the nominal activities of the sources and those determined by the dosimetry. Attention was then turned to the nominal activities.

Neutron absorption calculations are generally used by the makers of such sources to predict activities of irradiated samples. The relationship commonly used is

$$C = \frac{0.6\phi\sigma Mr}{3.7 \times 10^{10} A}\left(1 - e^{\frac{-0.693t}{T}}\right) \quad (9)$$

where C = total activity of isotope

produced (curies), ϕ = thermal neutron flux (particles/cm²/sec), σ = activation cross section (barns), A = atomic weight of irradiated isotope (gm), t = length of irradiation (arbitrary time units), T = half-life of isotope produced (same time units), M = mass of element present (gm), and r = fraction of irradiated isotope present.

Of these factors, A is known accurately in most cases, and t may be measured accurately. In the case of cobalt-60, with a half-life of the order of five years and irradiations of the order of months, one is still on the nearly linear portion of the activation curve. Differences of 5% between cobalt-60 half-life determinations cannot be considered as significant contributions to the discrepancy under discussion.

There are several reasons for difficulty in accurate determination of neutron-flux density, ϕ, and activation cross section, σ:

1. Calibration of the reference source used in determining ϕ and σ is quite complex. However, it seems unlikely that such a factor could explain a threefold error.

2. The neutron-flux spectrum cannot be considered a significant factor since capture of neutrons at nonthermal resonance energies would give too low a computed value rather than the observed high value.

3. Local neutron depression caused by the insertion of irradiation samples of high cross section seems the most probable source of the observed discrepancy. Recent work of Levin and Hughes (*6*) indicates that this correction is of the order of magnitude of the observed discrepancy.

* * *

The figures appearing in this article were prepared by Mr. R. L. Kinney in collaboration with the drafting and the photographic services of the Engineering Research Institute of the University of Michigan. The numerical calculations were conducted by Mr. E. M. Rosen and Mr. R. D. Pierce.

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Discontinuous Servo

Principles of the CP-3′ reactor's control system are used to illustrate the desirability of discontinuous-type servo systems for regulation of power reactors. Such systems are simple, compact, and economical from both the initial cost and maintenance standpoints

By J. M. HARRER and J. A. DESHONG, Jr.
Remote Control Engineering Division
*Argonne National Laboratory**
Lemont, Illinois

A DISCONTINUOUS-TYPE reactor power regulator is simple and compact. It uses a reactor's inherent stabilizing characteristics to reduce wear on the control-rod drive mechanism. The dead-zone discriminates against power signal noise.

This article considers means of applying discontinuous-type regulation, as used on the CP-3′ research reactor, to a power reactor. Attention is focused on the control elements that accomplish the regulation of reactor power to a preset value. The preset value itself is automatically controllable either by the operator or by the plant output requirement.

General principles of control of nuclear power reactors have been described previously (*1*). An early paper (*2*) demonstrated that neutron density, n (a measure of reactor power), can be regulated by an absorber rod displaced in a corrective direction by rod-driving motors whose speed is proportional to both $(n - n_0)$ and the first derivative of n, where n_0 is the starting or reference point. This system was successfully used to control the first reactor (CP-1).

The use of the derivative stabilizes any elementary feedback control system. Basically, the reactor is an integrator, whose output power, n, may be expressed as

$$\frac{n(t)}{n_0} = K \int \delta k \, dt$$

where it is assumed that both δk and the difference between n and n_0 remain small or nearly zero. Derivative control has the general effect of offsetting this inherent integrating property of the reactor.

Fairly precise control can be obtained manually with the operator observing the flux error and rate of change and then controlling the speed and distance of rod movement. But automatic control can be made stable and more precise.

Manually controlling a reactor at a

* Operated for the Atomic Energy Commission by the University of Chicago.

for Control of Power Reactors

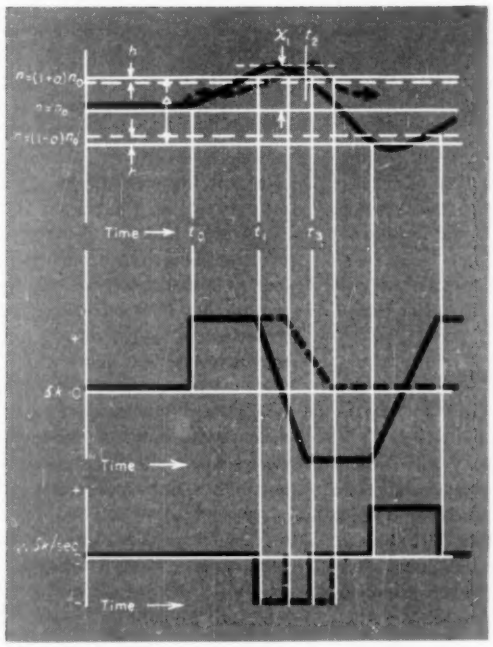

FIG. 1. Contactor control operation. Time-domain

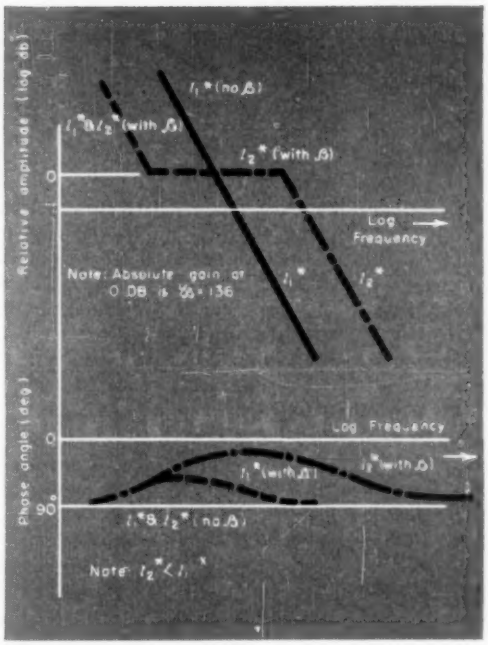

FIG. 2. Reactor Bode diagram. Frequency-domain

set value for a long time can become a very monotonous job for an operator. Automatic regulation is essential.

From manual operating experience with the CP-1 reactor, W. H. Zinn and his associates observed that when the galvanometer (indicating extent of power level deviation from the desired value) had moved a few centimeters, it was time to move the rod a fixed distance in a corrective direction. It seemed obvious that, instead of having a regulating system with an error-plus-derivative velocity response, all that was needed was a means to set the rod in motion in a corrective direction at a fixed velocity when the galvanometer reading exceeded the error value. The device also would stop the motion when the deviation was less than the error value. The speed at which corrective δk should be inserted, and the deviation allowed before starting corrective action were both determined by observation. An automatic system was designed to carry out these functions.

The heart of the system was a light-beam galvanometer whose deflection was observed by a pair of photocells. Stable operation was obtained under most conditions of operation. The basic system is still in use on the CP-3′ research reactor at ANL (*3*). This type of control is basically a discontinuous-feedback control system with a preset saturation velocity (or gain) that is opposite in sign to the error. It can be analyzed by known methods (*4*, *5*).

PRINCIPLES OF ANALYSIS

Examination of this system leads to some interesting data, but even more interesting is the fact that such a system has been operated successfully on a nuclear reactor. The CP-3′ reactor is used for experimental purposes and, therefore, this experience is not directly applicable to a power reactor. However, more can be learned about how to design for a wider field of application if the performance of this system is investigated.

Time Domain

Figure 1 shows how a discontinuous system controls a reactor when the reactor is assumed to be a perfect theoretical integrator. This was the assumption used in the first design for CP-1. The control system will supply either negative δk/sec at a velocity, $-v$, if h exceeds $(1 + a)n_0$; or positive δk/sec at a velocity, $+v$, if n is less than $(1 - a)n$. It will remain inactive between these values.

The value Δ is the total inactive zone of which a fraction h represents the change in n required to de-energize the motor. This value represents the contactor hysteresis. It results from the fact that the current in a contactor coil must be substantially reduced below the pull-in value before the contactor will open.

The reactor is critical ($\delta k = 0$) until time zero. At t_0 a very small increase in δk is inserted. The power, n, rises until it exceeds the $(1 + a)n_0$ value at t_1. The motor starts to insert negative δk, returning δk to zero at a point, x, with the power still outside the Δ zone. The power re-enters the Δ zone at t_2; but due to the effect of hysteresis, the motor continues to run until t_3, at

which point the δk value is negative. The power will then fall until $(1 - a)n_0$ is reached at which point the cycle is reversed. This is a pure oscillatory condition.

The delayed neutron groups change the reactor from a pure integrator so that the power rise after t_0 is along an exponential curve (*1*) like the dotted line in Fig. 1. When power exceeds the $(1 + a)n_0$ value, the corrective δk action is more effective in reducing power. The greater negative slope offers the possibility that the power could re-enter the Δ zone with the reactor critical. The steepness of the slope of the dotted power curve as it re-enters the Δ zone is also dependent upon the relation between the neutron mean effective lifetime, l^*, and the delayed neutron time constants. Reducing the l^* value increases the possibility that the reactor will re-enter the Δ zone with a $\delta k = 0$ value. The advantage of entering the Δ zone with $\delta k = 0$ is obvious since the reactor power will be more constant under this condition.

Frequency Domain

Figure 1 was drawn in the time domain. More quantitative data may be obtained from a frequency-domain analysis. When the amplitude and phase functions are considered in the light of well-known Bode feedback criteria (*6*), not only is stability displayed but a convenient method of quantitative analysis for design purposes is also outlined.

A frequency-domain analysis is presented in Fig. 2. The solid line represents the output-to-input ratio of a perfect theoretical integrator on a log amplitude or decibel (db) scale vs log frequency. The solid line on the lower plot is the corresponding phase, which for the pure integration case is 90 deg at all frequencies. The analytical and experimental bases for the application of the curves of Fig. 2 to a nuclear reactor have been described previously (*7*).

Basically, any motor causing a change in δk by driving a rod has the effect of introducing into the control loop an additional 90-deg phase lag. This occurs because the resultant δk is the integral of the velocity δk/sec developed by the motor. Hence, there is always at least 180 deg total system phase shift if it is assumed that the reactor is a perfect integrator.

The marginal value for even an underdamped feedback control is such that the system gain is reduced to unity at a frequency for which the phase shift is no more than 150 deg (*6*). In Bode's terminology this is called a phase margin of 30 degrees with reference to the 180-deg point where instability occurs.

It is not possible to secure this margin for any motor velocity or gain setting with the fictitious pure integrating reactor since the phase is always 180 deg or more for any gain point. Thus, the basic requirement of some form of derivative control is recognized just as it was for the proportional system for the CP-1 reactor.

When delayed-neutron groups are considered, the curve takes the general shape of the dashed line of Fig. 2, and the corresponding phase shift is lowered over a small frequency range. The system gain or motor velocity (δk/sec) can be adjusted to cause operation near the minimum phase-shift point. In the practical case, there will be more than 90 deg of phase lag from the motor. This situation will be covered later. At present we will continue to consider only the relative effects of the reactor characteristic.

Neutron-lifetime effect. The dot-dash line in Fig. 2 applies to a reactor whose mean effective neutron lifetime is shorter than that for the dashed-line case. The phase lag has been reduced even further (the effective single delayed neutron point remaining fixed), and it extends over a wider frequency range. Thus, it offers more range for stable control system gain adjustment.

Temperature effect. A further stabilizing effect is obtained from any negative temperature coefficient existing in the reactor. This may be defined as the inherent introduction of negative δk due to reactor temperature rise (*8*). The reverse would be true if a positive temperature coefficient existed. The temperature effect is due to many combined physical and nuclear effects in the core. The manner in which it effects the reactor transfer function will now be treated more completely.

Symbols

- n = neutron density, a measure of reactor power
- n_0 = neutron density or reactor power reference, usually used here as control demand value
- δk = effective number of thermal neutrons produced per thermal neutron absorbed, minus 1 (for finite reactor)
- δk_s = spurious δk to be offset by control
- δk_c = control δk manipulated by control system motor
- l^* = modified mean effective neutron lifetime for finite reactor
- β = total fraction of neutrons that are delayed
- v = velocity of control rod that is operated by power regulating system, δk/sec
- K_P = power coefficient of negative δk, δk/unit power change
- K_R = reactor gain, $136n_0$
- K_m = motor terminal velocity, δk/sec
- $K_0 = \Delta \times |g_{D_1}|$
- $|g_{D_1}|$ = contactor function (*4*)
- $G(j\omega)$ = forward transfer function characteristic
- T = time constant of feedback stabilizing network
- a = fraction above or below n_0 at which control system is activated, $2a = \Delta$
- Δ = control dead zone, per cent or fraction of n_0
- h = contactor hysteresis
- x = maximum power excursion away from n_0
- t = time, sec
- $j = \sqrt{-1}$
- ω = frequency, radians/sec

CONTROL OF THE CP-3′

An understanding of the principles underlying the operation of the discontinuous-type servo used in an existing research reactor will be useful in interpreting the manner in which the system's advantages are applicable to a power reactor.

Transfer Function

Figure 3 shows the transfer function or frequency-domain characteristic of the CP-3′ reactor. The solid lines represent the transfer function of the reactor at low power (*7*).

The reactor power change causes the reactor temperature change; therefore, the temperature coefficient is a power coefficient of negative reactivity. The power coefficient is not usually effective until about 10% of the design power is reached.

The diagram on Fig. 3 shows the power coefficient feedback loop existing within the reactor. $K_R G(j\omega)$ represents the frequency-domain behavior

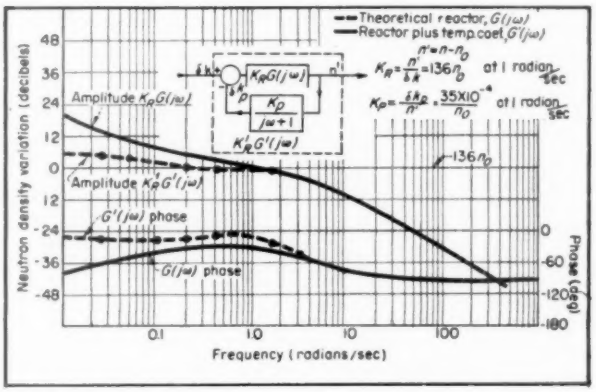

FIG. 3. CP-3 reactor transfer function (frequency domain)

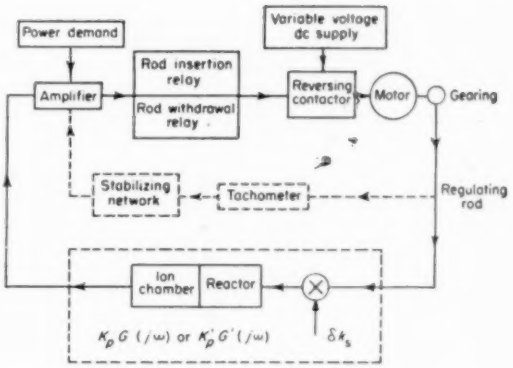

FIG. 4. Basic control diagram of CP-3′

for the reactor at zero power. K_P is the power coefficient in δk/(unit power-change). The power coefficient effect is always accompanied by a time delay due to the heat-transfer characteristics of the core. The effective delay in this case is about 1 sec. This effect is represented as $K_P/(1 + j\omega)$ and the loop is closed with δk_P representing the effective δk due to the power change. The loop effect was calculated and is shown as $K_R'G'(j\omega)$.

The effect of the power coefficient, as shown by comparing the curves, is to limit reactor gain at low frequencies for $K_R'G'(j\omega)$, which includes temperature effect, to plus 6.6 db. For the $K_RG(j\omega)$ case with no temperature effect, the reactor gain approaches infinity at low frequencies. It can be seen that with a temperature coefficient, a small positive δk will cause the power to rise only to a definite point. An infinite power rise would result without a temperature coefficient. The coefficient nullifies the reactor's integrating effect and eliminates the phase lag at low frequencies. The lag is reduced to 10 deg for a frequency as high as 0.01 radian. It was 77 deg for the $K_RG(j\omega)$ case at 0.01 radian.

As a result of the negative power coefficient, the steady-state self-stabilized power is proportional to the δk fed in. To change power, it is only necessary to displace the rod in a proportional manner similar to changing the coal injection rate to change power in a conventional power plant.

Control of a power reactor to plus or minus several per cent of demand power is probably satisfactory. A discontinuous-type control system on a reactor with a negative temperature coefficient is readily stabilized by lowering the regulating rod speed, but this means less control tightness. Tightness may be important on a research reactor.

The System

The application of the discontinuous-type control system to a research reactor will be illustrated by an analysis of the CP-3′ system.

The basic regulating loop (shown in solid lines on Fig. 4) will be used. The dotted curve does not apply to the system now under discussion. The existing CP-3′ system has, as an amplifier, a light-beam galvanometer whose deflection is proportional to the difference between a standard current and the ion-chamber current. As the galvanometer deflects, photocells are activated and close either the insertion- or withdrawal-motor relays. Gain adjustment is provided by varying the motor voltage, resulting in a speed adjustment.

The frequency-domain behavior of the elements of this loop is shown by the equations on Fig. 5. In the equations, the ion-chamber gain characteristic is lumped with the reactor characteristic. The ion chamber has flat gain and zero phase shift in the range of frequencies being considered. The cascaded behavior of these units is indicated on the log-polar-plane plot of Fig. 5.

Log-polar-plane analysis. The change from the Bode-type chart analysis, used so far in this discussion, to the log-polar-plane plot was made because the effect of the contactor can then be studied more readily. The mathematical basis for this chart is given in reference (*11*), but a brief description of its makeup and use will serve to clarify the discussion of system performance.

The ordinate of Fig. 5 is in decibels. The straight horizontal lines represent the normalized open-loop system gain. Unity gain (or 0 db) is obtained by dividing by the actual system gain figure, computation of which is shown in the Appendix. The abscissa is in phase degrees of lag. The straight vertical lines represent the open-loop system phase. Thus, at any frequency, the phase and gain of the system, shown in two curves on a Bode chart, are displayed by one curve on the log-polar-plane chart, and the frequency value is marked for each point on the curve. The center point of the chart, 180-deg lag at 0 db (or unity gain), represents an oscillatory condition for the control system. The control system phase margin, referred to previously as a stability criterion, is the number of degrees by which the system's curve passes to the right of this center point as the curve crosses the 0 db line. The phase margin as used in this article is 180 deg minus the phase lag read on the abscissa.

The superimposed coordinates represent the performance expressed as a ratio of output to input of a system closed upon itself with unity feedback. Thus, if the phase lag and gain, $KG(j\omega)$ of a system of elements are plotted on the rectangular coordinates, the phase lag and gain $KG(j\omega)/(1 + KG(j\omega))$ for the system with unity feedback is read directly from the curved coordinates. Under the generally encountered feedback control system conditions, the 0-db coordinate of the superimposed set represents the critically damped condition for a closed system. The ellipses to the left of this 0-db line are marked

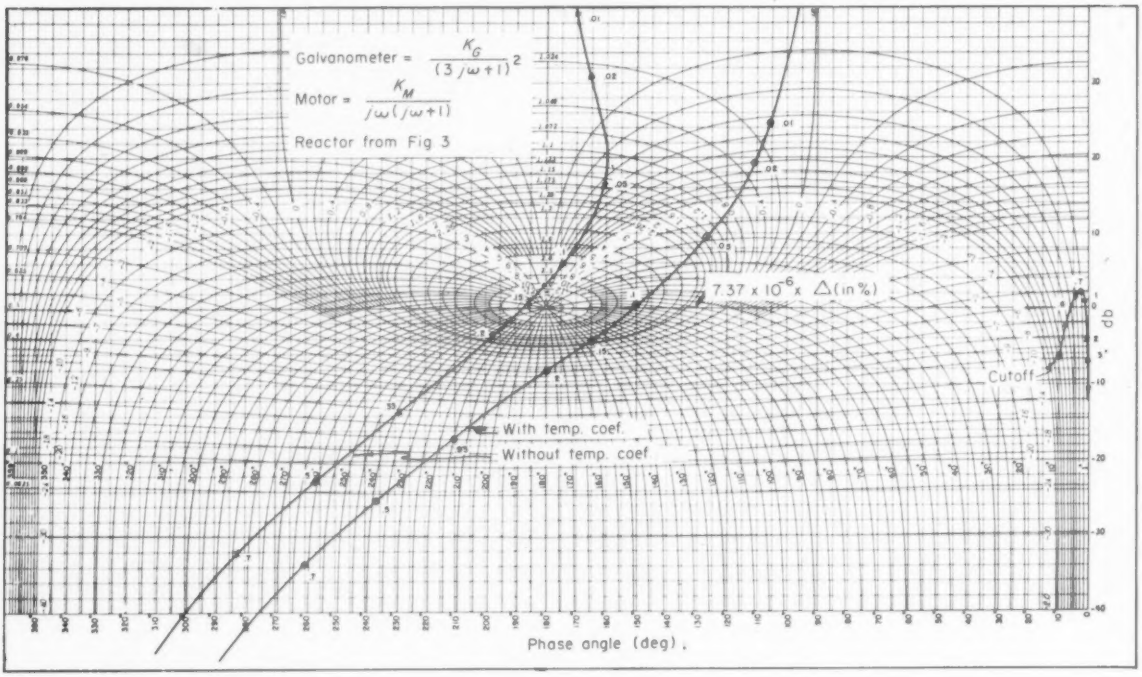

FIG. 5. Stability of original CP-3′ system

both in decibel and actual closed system gain values. Good practice in a linear feed-back control system design calls for its curve to be tangent to one of the ellipses between 1.3 and 2.0, establishing a compromise between very-oscillatory and critically-damped control system operation.

In this analysis, the frequency functions of the reactor control system are cascaded, starting with the spurious Sk_s input to the reactor and ending with the output or corrective Sk_c controlled by the motor-driven rod. This curve is plotted on the rectangular coordinates. The superimposed coordinates then represent the resultant closed-loop frequency response of the system when the rod offsets a spurious Sk_s introduced into the reactor.

Contactor effect. The effect of the contactor has been considered in the loop representation for a Δ of 0.01 or a control dead-zone setting of $\pm \frac{1}{2}\%$ of demand power.

The contactor presents an additional influence on stability that is indicated by the $\Delta \times |g_{D_1}|$ curve plot (*4, 10, 11*) at the right of Fig. 5. The error amplitude applied to the contactor is indicated by the points along this curve. The stability will vary with this amplitude, and the contactor's effect on stability will be shown by first plotting the curves representing the system frequency function on a transparency, along with the 0-db zero-phase point, and then laying this transparency over the chart and allowing its 0-db zero-phase point to traverse the contactor function. The relative stability, for different amplitudes of signal at the input to the contactor, is indicated by how closely the system curve approaches the 0-db 180-deg point. The system's maximum overshoot is read from the superimposed set of gain coordinates; phase margin, from the abscissa.

The contactor curve shown is for an h/Δ ratio of 0.03. Increasing h causes the start of the curve (the cutoff point at the left) to shift toward increasing phase lag and toward increasing decibels, both of which contribute to increased instability (*6*).

The contactor effect is relatively minor for the 0.03 h/Δ value used. For the sake of clarity, the contactor effect will not be considered beyond this point. However, it must be emphasized that securing this small h/Δ value is one of the difficulties of designing this type of system. This value is one of the most important measures of system quality.

The curve of Fig. 5 for no temperature effect shows the unstable situation (continuous rapid changing of power back and forth through the dead zone) described earlier in connection with Fig. 1. To stabilize the system represented by this curve, the gain (motor speed) must be lowered until the greatest phase margin at 0 db is obtained. This means moving the curve down until the point representing 0.05 radian/sec is on the 0-db line. At best, only about 22 deg of phase margin can be obtained. This is the minimum recommended (*9*). To obtain this condition, a rod or motor velocity of 1.2×10^{-6} δk/sec must be used. (For calculation of terminal velocities, see Appendix.)

This velocity is well below the value obtainable from the motor on CP-3′. To stabilize the system at low power, the Δ zone is opened up to about $\pm 10\%$. This effectively is a gain reduction since the contactor gain is inversely proportional to Δ.

As plotted, the curve reflecting the temperature effect of power has the generally accepted good performance value of 30-deg phase margin. As shown later, more desirable operation would be obtained if there was a phase margin of about 60 deg. This can be accomplished by a gain reduction of about 12 db, which gives a rod velocity of 1.86×10^{-6} δk/sec. This again is

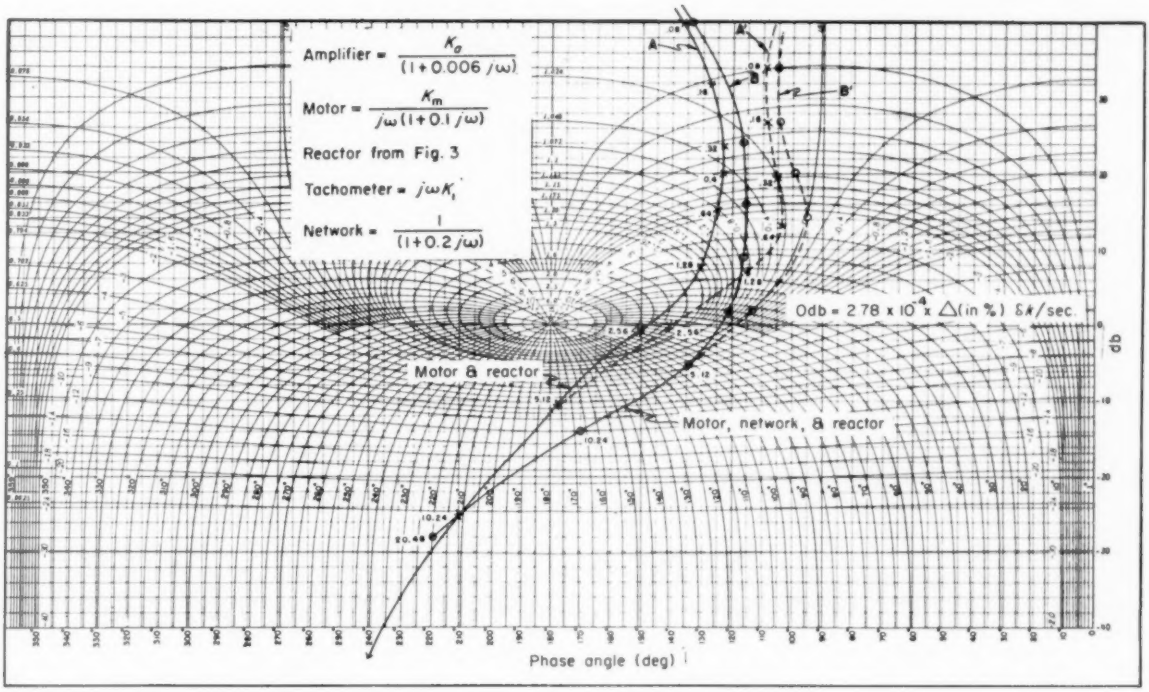

FIG. 6. Stability of redesigned system

below the range of the motor's speed, so the Δ zone is widened to about 4%. This results, as before, in a gain reduction without a further lowering of the motor speed.

POWER-REACTOR CONTROL

The CP-3′ system does not permit convenient changing of power while in automatic control. It is necessary to put the reactor on manual control, change the power, and then reset the automatic system.

Design of a system that would provide automatic power-level adjustment over a range of 1–100% of full power was undertaken. It was to provide a uniform Δ of 1% of the selected power level setting anywhere between 10 and 100% of maximum power. It would increase uniformly through the 10–1% power range to a Δ of 10% at 1% power. The system would also possess good stability at all power levels for one fixed motor speed. In other words, it must be possible to leave the motor speed setting unchanged under all conditions of operation.

Design Procedure

The first steps involved eliminating the phase lag of the galvanometer and reducing the motor phase lag by using a motor with a faster time response. A stabilized double-ended d-c amplifier was substituted for the galvanometer and photocells. The amplifier output closed relays as shown in Fig. 4.

The tube complement of the amplifier was limited to two amplifier tubes and one relay-control tube. The small tube complement was made possible by using a specially-designed ion chamber giving 250×10^{-6} amperes at full reactor power, with a dynamic impedance at this current level in excess of 10^8 ohms. The amplifier input impedance at full power was 5×10^5 ohms, increasing to 5×10^6 ohms at 10% power and below. The ion chamber was designed to maintain 10^2 times these values in the range indicated.

The low h/Δ of 0.03 in the galvanometer system resulted fundamentally from mechanical adjustment. In the new amplifier system the 0.03 value was obtained by using sensitive relays and a base current many times the current required for relay pull-in. A new motor with the frequency domain characteristics shown in Fig. 6 was used.

The control loop was set up as in Fig. 4, omitting the minor loop feedback shown dotted. Using the same procedure as before, the curves A and A' of Fig. 6 were obtained. Curve A' reflects the temperature effect of power.

The A curve indicates a phase margin of about 60 deg at a frequency of about 0.4 radian/sec, with a speed of 2.78×10^{-4} δk/sec (see Appendix). This takes into account the fact that Δ is 10%, the value allowed at 1% reactor power. At 10% power, the dead zone is automatically closed up to 1%, and the phase margin for the same speed is reduced to about 33 deg, assuming no temperature effect. With temperature effect considered, 42 deg of phase margin are obtained for the same speed.

Optimum Correction

When the system represented by curve A' of Fig. 6 controlled the CP-3′ reactor, the minimum correction observed under relatively stable reactor operating conditions was 4×10^{-5} δk, a relatively large value. Some indication of the optimum correction size required for this particular reactor is obtained from the following approach.

An average peak-to-peak noise of 0.2% of n_0 was observed in the electric signal representing the reactor flux. It probably results from movements of reactor core components or moderator and represents δk variation in the reactor that we do not want to follow since it is recurrent and tends to average out to zero. The signal noise rep-

resents the prompt response of the reactor to the δk variations.

If the power demand value is set at 100% and the reactor power is actually 100.4%, just inside the Δ zone, high peaks contained in the average 0.2% peak-to-peak value of noise would have a tendency to exceed the Δ zone upper limit of 100.5% and would cause a corrective rod movement. If the steady reactor power were 100.3%, the tendency for a correction due to a noise peak would be greatly reduced because of random distribution of noise peaks.

This suggests that an optimum δk correction by a control system should result in a prompt change in reactor power level of 0.1%, thereby greatly reducing the possibility of a second correction in the same direction. This reduces the number of contactor operations per unit time. The power value will, for these small rapid δk changes, vary directly as δk according to the prompt neutron response of

$$(n - n_0)/n_0\ (\%) = 1.36 \times 10^4\ \delta k$$

and the power change will occur in less than 1 sec. Using the 0.1% correction value, we obtain a δk of 7.4×10^{-6}. This δk would result in a reactor power with a period of about 10,800 sec. Assuming that the reactor was critical when the correction occurred, the reactor power will start downward on this slow period until it reaches a value of 99.6% power, at which time the noise will cause a correction in the reverse direction.

The time that elapses between optimum δk corrections is calculated to be about 75 sec for the conditions described. In the actual case, of course, the reactor probably would have been slightly supercritical at the time the cycle started. Therefore, the correction interval would be somewhat longer than the 75 sec calculated. There would be about 14 sec between corrections for the system shown by curve A' of Fig. 6 because the correction obtained under the stability conditions shown (correction size observed on the reactor was stated as $4 \times 10^{-5}\ \delta k$) is much larger than the optimum value.

The correction size is inversely proportional to phase margin. Therefore, the phase margin must be increased if the required optimum δk correction is to be realized.

Performance

Normally, the improvement could be obtained by using a phase-led network in the forward transfer characteristic. However, the increased noise amplification resulting from this approach renders it useless in this case. Adding the tachometer feedback, shown dotted in Fig. 4, provides a means of getting the desired stabilization without encountering the noise amplification problem.

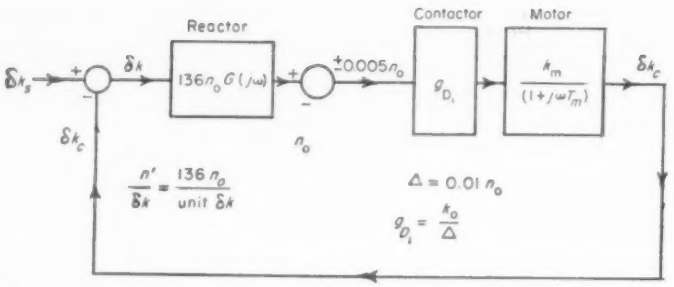

FIG. 7. System gain diagram

The minor stabilizing loop, consisting of the amplifier, contactor, motor, and the tachometer (without the network), shown in Fig. 4, has the characteristic of multiple unidirectional-type corrections due to the fact that the contactor harmonics are enhanced rather than attenuated by the tachometer. A basic assumption throughout this analysis is that the contactor harmonics are attenuated by the system characteristics in the path between the contactor output and the contactor input (4).

A simple network to reduce harmonics is

$$\frac{V_0}{V_i} = \frac{1}{1 + j\omega T}$$

If T is carefully chosen, large amounts of phase margin may be obtained as shown by the curves B and B' of Fig. 6 where a T of 0.2 was used. The phase margin from curve B (no temperature effect) is 57 deg and the phase margin from curve B' (includes temperature effect) is 62 deg. The temperature effect is now contributing only about 5 deg of phase margin whereas the network plus tachometer are contributing about 22 deg. All these values are taken at the base motor velocity for Fig. 6 of $2.78 \times 10^{-4}\ \delta k$/sec. (See Appendix.)

The δk correction made by this system while controlling CP-3′ was 9×10^{-6}. This compares favorably with the optimum value of 7.4×10^{-6} calculated previously. It verifies the inverse relationship between correction size and phase margin. This yields a calculated time between corrections of about 70 sec. Again, this is slightly shorter than would be obtained in practice due to the fact that the reactor will not be exactly critical when the correction occurs. The correction interval observed during operation of the system on the reactor was about 80 sec. The difference of about 10% between these values enables calculation of how far the reactor is from critical, on the average, when a correction occurs. In the preceding case, the δk value resulting from such a calculation is 8×10^{-7}. This shows that this data was taken after the reactor had been operating for an extended period of time and had reached a good state of equilibrium.

The experimental work described was carried out on a research reactor where the control tightness of $\pm 0.5\%$ was useful. This tightness probably would not be necessary on a power reactor.

If tightness is relaxed, that is, if the dead-zone size is increased, the correction interval would be lengthened proportionally, leading to even less severe duty on the control elements.

The stabilizing effect of the temperature coefficient is absent at lower powers. Therefore, if desirable control stability is to be obtained throughout the entire power range from 1–100%, the system must be designed for absolute stability without depending on the temperature coefficient.

With a given reactor characteristic, a given motor time-constant, and a given Δ zone, there is a definite rod speed, at low power, for which maximum stability or optimum operation can be obtained. An example of this is the 0.4-radian/sec point of curve A of Fig. 6. After this optimum speed is determined, it should remain fixed for operation at all powers. Compensation is secondary and should be used only as needed by consideration of

the over-all system characteristic. However, compensation of the type used in these experiments will probably always lead to the advantage of securing smaller (more nearly optimum) corrections under stable operating conditions.

The system as set up for CP-3′ has all the elements required for control of a power reactor. The system includes a mechanical link called "Power Demand" in Fig. 4 by means of which the reactor power can be matched to the plant demand by a second control loop.

APPENDIX

Gain Computations

The major difficulty encountered in using the curves of Figs. 3, 5 and 6 is the calculation of the actual terminal velocity in δk/sec represented by the value 0 db.

In Fig. 3, the 0-db value is established as 136 n_0 at 1 radian/sec, where n_0 represents the base reactor power about which a variation n' will occur due to a harmonic reactivity variation of magnitude δk (7). The $K_R G(j\omega)$ curve of Fig. 3 is plotted at this value. The effect of the small K_P feedback is reflected in the $K_R G'(j\omega)$ on the same figure.

The loop shown in solid lines in Fig. 4 is detailed in Fig. 7 to assist in understanding Figs. 5 and 6. The reactor normalizing factor is $1/(136n_0)$ at 1 radian/sec to obtain unity gain at this point since the reactor gain is $136n_0$. The K_m motor-gain line is passed through 0 db at 1 radian/sec, and the sum of the deviations for the motor and the reactor is plotted as a function of frequency on the log-polar-plane charts of Figs. 5 and 6. Thus, the reference line at 0 db represents unity loop gain disregarding the reactor gain. Therefore, the K_m was reduced below unity by both the reactor gain and the contactor gain of $1/\Delta$ (4).

$$K_m(j1) = \frac{1 \text{ radian/sec}}{136n_0/\text{unit } \delta k \times 1/\Delta}$$

$$K_m(j1) = \frac{1}{136n_0/\text{unit } \delta k \times 1/0.01n_0} = 7.37 \times 10^{-5}\ \delta k/\text{sec}$$

To get the curves closer to stable operating values, the entire loop gain was lowered 20 db (10 times) for the chart of Fig. 5. Therefore, 0 db in Fig. 5 becomes 7.37×10^{-6} δk/sec, one-tenth of the value calculated previously. The K_0 of the contactor is plotted about this value by simply plotting 20 $\log_{10} K_0$. This number is calculated for h/Δ of 0.03 from the method of reference (4).

The over-all gain in Fig. 6 was again assumed as unity and K_m was raised 3.78 times (11.6 db) at 1 radian/sec instead of 0 db as in Fig. 5. This was done to shift the curves into a more convenient location for discussion. In this case

$$K_m(j1) = \frac{3.78}{(136 \times 100)} = 2.78 \times 10^{-4}\ \delta k/\text{sec}$$

Both values for K_m of Figs. 5 and 6 have been calculated for a Δ of 0.01; then, if Δ is changed to 0.03 for a 3% zone, the gain is simply multiplied by 3. Hence, values recorded on the figures are simply multiplied by the dead-zone Δ in per cent to obtain the gain for different dead-zone values.

* * *

The authors wish to thank H. L. Hull for his encouragement and direction during the carrying out of this project and the following people who contributed to the success of development work: W. H. McCorkle and his staff who supplied reactor data and gave general assistance in setting up the control system on the CP-3′ reactor; W. C. Lipinski who helped build equipment and record data; A. R. Snyder who assisted with computations; S. G. Kaufmann who designed and built the ion chamber; J. J. Dickson who did the mechanical design of the rod drive, and J. H. Dyer who supplied the motors and electric power equipment. Equipment used in the original galvanometer controller was built and installed by T. H. Brill.

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The Importance of Symbols

SYMBOLS ARE ENORMOUSLY IMPORTANT. Take patents, for example. I find among engineers and scientists that, whether or not the patent clauses of the present Atomic Energy Act are a real block to the development of atomic power, they have become a symbol of such a block, and this symbol tends to slow down progress. The same is true of secrecy. Many people come forth in connection with their professional activities and say, "We can't do this or that because there's too much secrecy." Careful examination may prove that secrecy isn't blocking their situation at all, but secrecy has become a symbol. They believe they cannot do it, so it is not done.

After seeing the effect of Mr. Churchill's "V" in the last war, I think we cannot underestimate the effect of symbols. They undoubtedly contributed to the victory. If changes in our atomic law would do nothing more than establish new symbols that lead people to believe they can achieve progress, then this is sufficient cause to make the modifications.

—Lloyd V. Berkner, president, Associated Universities, Inc. at conference of Atomic Industrial Forum, Nov., 1953

RADIATION STERILIZATION V

Evaluating the Safety of Radiation-Sterilized Foods

This article represents the first time the Food and Drug Administration has put its official position on radiation sterilization in writing

By A. J. LEHMAN and E. P. LAUG
Division of Pharmacology
Food and Drug Administration
Department of Health, Education, and Welfare
Washington, D. C.

BY ITS VERY NATURE radiation sterilization, i.e., the process whereby it is proposed to destroy microorganisms by exposure to streams of high-speed beta particles or gamma rays, can be expected to produce more subtle changes in molecular structures than heat sterilization. It is very probable that the process, when perfected, will produce a major revolution in the preparation of foods and drugs. The Food and Drug Administration should approach this new technique with a great deal of conservatism, and yet be conscious of its responsibility not to raise artificial and unrealistic barriers that might impede progress.

It can be said that a good measure of the conservatism stems from the suspicion that some of the so-called classical methods for the evaluation of safety, wholesomeness, etc, may not be entirely adequate. This situation is brought into even sharper focus when it is remembered that the process of radiation sterilization, particularly with respect to food, may eventually become far more extensive than heat processing. Thus it is conceivable that a type of flash pasteurization may be applied to enhance the keeping qualities of numerous fresh fruits and vegetables, many of which are ordinarily eaten raw. It is not too unlikely to assume, therefore, that eventually a far greater proportion of the dietary of man may be subject to radiation process than now receives heat processing.

Orientation of Testing

Before embarking on extensive and expensive animal experimentation, the process of radiation sterilization should be clearly oriented along these lines:

1. Minimum dosage of beta and gamma radiation necessary to effect commercially satisfactory sterilization.
2. Minimum dosage of radiation that can produce clear and well-defined deterioration of the product with respect to toxicity and/or wholesomeness.
3. Acceptability of the "minimum dosage" processed food on the basis of texture, taste, smell, keeping qualities, etc. And it should be obvious that the last consideration will be the most potent arbiter as to whether any investigation whatever will be conducted on the safety of the product. Since this subject has come in for extensive consideration elsewhere (*1*), no further mention need be made here, and it will be assumed that all products to be tested for safety have successfully passed the acceptance hurdles.

"Proper" Irradiation

It is suggested that tests on safety be conducted with products "properly" irradiated to give the desired degree of sterilization with least amount of quality deterioration. The investigator should be aware, however, of suspicions aroused within an area of negative tests, and give attention to a deliberate exaggeration of dosage to define a factor of safety where it seems desirable.

Some justification of deliberate overdosage may be required: (a) It is fairly certain that all the situations under which radiation sterilization of even a single product may be applied cannot be entirely anticipated. (b) There is the possibility of failure of proper control of either time or intensity of exposure to radiation, whether deliberate or accidental. (c) It is probable that frank and well-defined overt effects of radiation on wholesomeness of a product will be difficult to produce.

Hence the investigator should not be lulled into a false sense of security by a montonous procession of negative results. This thought is not added to imply that the positive result should necessarily always be deliberately sought. Nevertheless, the positive result, *when weighed in its proper frame of perspective*, does give more information, and at least defines tendencies.

How Much Research?

In properly assessing safety and wholesomeness, the general axiom may be sounded that the amount of critical study of a process, a food, a drug, etc, is necessarily roughly proportional to the universality of application.

It becomes necessary, therefore, to critically review again all of the methods that are available and in current use for testing safety and wholesomeness. Basic studies have already been outlined in Procedures for the Appraisal of the Toxicity of Chemicals in Foods" (*2*), and principles have been laid down by the Food Protection Committee of the National Research Council (*3*) in cases where animal studies are involved. Some details have been

elaborated in these publications and need not be repeated here. It is proposed, however, to examine areas where these methods may, in their present form and conception, fail to give proper evaluation of an irradiated food, and to suggest newer techniques as well as improvement of the older.

It should be reiterated that all foods, etc, must eventually be tested on man himself. It is not beyond the realm of possibility that even the most elaborate studies on animals will have failed to bring to light some significant factor that may prove harmful. A certain calculated risk is always involved; however, such a risk should never be considered in a process where merely economics is involved. That is to say, we should be willing to encounter more risk where it can be shown that radiation sterilization is the only satisfactory method, and where standard heat sterilization destroys or seriously modifies a product. On the other hand, if no "must" is involved and the two processes are equally applicable, it must be certain that little or no risk results from radiation sterilization. Here the evidence of safety would be very carefully surveyed, particularly if it involves a large segment of the diet.

Animal Studies

Because of the importance of the proteins in the dietary, their complexity and well-known lability, the suggested animal tests are intended to apply chiefly to these substances. With proper modifications these tests can be extended to fats, carbohydrates, and other food factors.

Tests on irradiated protein in which animals are used should be made to determine two things: toxicity, and nutritional adequacy. By their nature, the two types of tests are mutually exclusive and cannot be carried out simultaneously in the same group of animals. For uncovering toxic effects the animal should be challenged with a relative excess of the substance under study; for nutritional adequacy the challenge is made by reducing the supplement to the point where inadequacy becomes magnified.

Supplementation is most easily accomplished by adding the irradiated protein to a protein-free synthetic diet. If attempts are made to challenge for toxicity, from 2 to 3 times the normal protein requirement should be added.

It can be expected that in the case of irradiated proteins, gross toxic effects will not occur and possibly minimal effects may be undetected. This supposition is based on the likelihood that radiation produces changes in proteins that are qualitatively if not quantitatively similar to those induced by heat. And in the latter process there is certainly a large background of experience indicating lack of toxicity. Hence in setting up an animal feeding study, it is desirable to include an "internal standard of reference" in which heat-sterilized protein is fed at the same challenging level. It is suggested that a complete study include three groups of animals as follows:

1. Control group. In this group the protein supplement is not processed. This is an expensive and technically difficult part of the procedure, since it involves preparation of a diet whose keeping qualities may be poor (meat protein). However, with the aid of refrigeration or freezing applied to all diets, it is possible to circumvent these difficulties. In addition, there should be included adequate bacteriological studies to rule out the possibility that pathogenic organisms could vitiate the results.

2. Experimental group. In this group the protein supplement is heat-sterilized, the degree of sterilization being bacteriologically controlled to see that it is adequate and comes within limits of standard commercial practice.

3. Experimental group. In this group the protein supplement is radiation-sterilized to the same degree as by heat. This consideration is highly important because radiation sterilization, to be accepted commercially, must be judged by the same bacteriological criteria that are applied to heat sterilization.

The three animal groups suggested should be studied over the period of their lifetime. Since rats are most likely to be used, this includes an interval beginning at weaning and extending to approximately 2 years, a time when about half of the population will have died as a result of senescence. To allow for good statistics, the starting number of animals in each group should be about 40 equally divided as to sex. Part of each group should be bred and the dietary regimen carried through at least three generations. Generally little is learned from maintaining each successive generation through its complete lifetime, the matter of chief interest being fertility, size and weight of litter, number of litters, etc, which need be observed only during the first year of life of the particular generation.

Safety Tests and Stress Groups

The type of experiment suggested is an accepted procedure for evaluating the safety of a substance that may eventually find its way into the human dietary. It presupposes also that all surviving animals and those exhibiting gross symptoms are examined histologically and an attempt made to ferret out minimal disease processes. This is often difficult, as illustrated by the case of DDT. Here a certain type of characteristic liver injury (*4*) is minimal at the lower levels of intake and may actually be difficult to expose. Furthermore, numerous instances of morphological tissue changes that result from a variety of insults, are usually magnified under the stress of age. Such injuries may in fact go completely undetected if the animals are examined while still young and growing.

This points up one important aspect of animal experimentation that seems to have been neglected, namely, the "stress group." Usually, animal experimentation is aimed at a very different target. A group is selected on the basis of maximum homogeneity, and the experiment carried on with great pains to maintain the uniform animals in a uniform environment and to present only one challenge, that is, the substance or treatment under investigation. It is quite obvious that such experimental conditions are designed to reduce the number of variables and make it easier to interpret the results. However, it can also be said that such an experimental arrangement, by its very nature, may be limiting the number of answers that might be obtained. One may quite reasonably ask this question: "How would the uniform animal group have behaved if by some means the efficiency of the liver had been reduced by 25%?"

The very uniformity of response of a uniform group, under no stress but that of the experimental substance, makes it difficult to interpret the findings in terms of man, and after all, such interpretation is the ultimate purpose of a large part of animal experimentations. Man as a group is probably as heterogeneous as we can find in nature. It would indeed be difficult to find a group of so-called "normal" human beings

that did not represent a multitude of perhaps "dormant" stress situations. The difference in response to food alone has been nicely epitomized by the old saying, "One man's meat is another man's poison."

It would seem desirable, therefore, to supplement the tests as outlined on "normal" groups with tests on "stress" groups.

From the foregoing remarks it should not be implied that a deliberately heterogeneous group of animals be selected for study. Such a procedure would be self-defeating since the number of variables would make it difficult to gain a statistically valid result. It would be desirable, however, to produce animal groups from uniform stock in which a stress situation has been developed. For example, it should be possible, by giving a hepatotoxin such as carbon tetrachloride, to maintain a "sick" liver. Experiments on acute toxic response of animals to insecticides during a short period in which they received from 0.5 to 1.0 ml/kg of carbon tetrachloride have been carried out successfully in this laboratory (*5*, *6*). It remains to be seen whether upon adjustment of dosage a chronic state of liver impairment might be maintained.

Possibility for other stress situations should be mentioned: nephrotoxins (uranium or mercury salts); disturbance of thyroid function (thiouracil); disturbance of pancreatic function (alloxan); experimental anaemias, and finally, as a special category, cancer-sensitive animals. This latter type of stress group has been highly developed for uniformity of response.

It must be emphasized again that uniformity of response in a particular stress group is most desirable, but it cannot be decided at this time whether it would be possible to maintain all such proposed stress groups and keep them reasonably uniform over a normal lifetime. However, experiments, even if limited in time by increased morbidity of groups, would be extremely valuable. Thus, by interacting a number of well-defined functional inadequacies with the particular test substance, it becomes possible to define with somewhat greater assurance what the response of heterogeneous man might be —the well man, the sick man, the man whose liver is slightly abnormal but for whom no present clinical hepatofunctional test is definitive, and for whom final diagnosis comes at postmortem.

In reviewing the situation with regard to the adequacy of animal tests to define safety, it becomes obvious that the number of animal groups that could be suggested would rapidly outrun most laboratory facilities. A certain amount of judgment, strengthened by collateral tests or practical and theoretical considerations will usually decide what a reasonably good estimate of safety will be. If, for example, routine tests with "normal" groups give a positive answer, there would probably be little reason for compounding the test with a stress group. On the other hand, a negative response on a test substance in a "normal" group should not always lull the experimenter into a false sense of security, particularly when that test substance might have very wide contacts with man.

Nutritional Adequacy

Animal tests to demonstrate nutritional adequacy are well developed. They frequently follow the pattern indicated for testing safety. Because nutritional failures sometimes affect reproduction, it is particularly desirable to conduct experiments along such lines. Many of the vitamins are now chemically characterized, or can be assayed by means of microorganisms; thus it may be possible to forego some of the more elaborate feeding tests.

The modification of the nutritional properties of proteins by heating is well known, and it is very likely that similar effects will be produced by radiation. Physical changes such as coagulation, differences in solubility, etc, to name only two, undoubtedly produce differences in digestibility. It is the opinion of the authors that before extensive animal experiments at restricted protein levels are initiated, proteins that have been radiation-processed should be assayed *in vitro* for digestibility. Such experiments can be conducted readily and, in fact, even with human digestive juices. It would be desirable to use crude digestive juices as well as single purified enzymes. Rate of hydrolyses and end-product should be studied. Parallel tests should be made with heat-sterilized preparations, and if possible, on nonprocessed, as control.

Antigenicity

Since radiation might alter the allergenic properties of protein, its effects in this direction should be explored. By the use of "primed" animals, great sensitivity can be achieved, particularly when the histamine response is bioassayed on intestinal strips.

Enzymes

So far, the available evidence indicates that radiation energy sufficient to kill microorganism does not destroy many enzyme systems that are easily destroyed by heat. For example, radiation-sterilized milk on standing becomes unpalatable because of the activity of certain proteolytic enzymes. These enzymes carry the process of protein degeneration to a stage giving rise to amines.

The significance of this fact can hardly be overestimated. It may well become the limiting factor in the keeping qualities of otherwise sterile and initially wholesome irradiated food. It follows, therefore, that the enzymology of proteolytic systems be carefully studied. It may even be suggested that assay methods dealing with the detection of amines be developed to follow keeping qualities.

Chemical and Physical Methods

Chemical and physical methods have several important relations to the study of radiation effects on foods. First, they may give important clues to the degeneration or modification of molecules under the impact of radiation. This may lead to the discovery of toxic by-products or evidence of destruction of useful accessory food factors. Second, they may be extremely useful in studying the intermediary metabolism of radiation-modified substances in the animal body. Generally speaking, therefore, chemical and physical tests should always precede animal tests, for the advance clues may enable the investigator to plan the animal experiment with greater intelligence and insight. In some instances even, animal experiments may be omitted when a "radiation" product has been adequately characterized.

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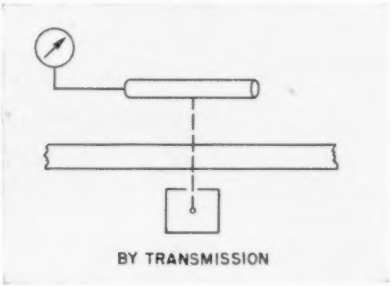
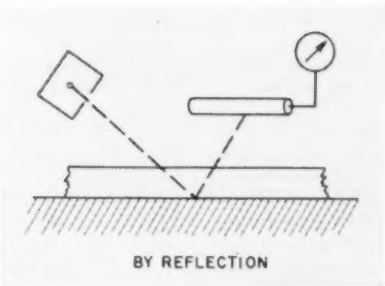
For measurement of . . .

THICKNESS





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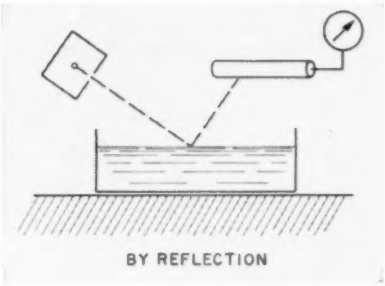

. . . this article tells how to get . . .

The Best Performance from Beta Gages

By L. R. ZUMWALT
Tracerlab, Inc.
Berkeley, California

INDUSTRIAL PROCESS controls with beta gages as the primary indicators can be made most useful when the characteristics of the gages are known quantitatively. This article presents a means of analyzing the application of a beta gage to any particular process.

Thicknesses of continuously moving materials and the concentrations of process solutions are the quantities most commonly measured with beta gages (*1–5*). Measurements are based on two principles. The absorption of beta radiation as it passes through a material provides an indication of the material's thickness. The degree of backscattering of beta rays from a substance can be used to determine either thickness or concentration.

Mathematical Formulation

A quantitative analysis of beta-gage sensitivity, accuracy, and response time requires the mathematical formulation of beta-ray transmission and reflection.

Approximate relationships between the observed current from the ionization chamber and the thickness or concentration (variables that determine the number of beta particles entering the ionization chamber) are given in this section.

Thickness-by-transmission. When the material measured is between the radiation source and the ionization chamber

$$\Delta I = I - I_0 = -I_0(1 - e^{-\mu_a x})$$

With reference (meter zeroed) at $x = x'$

$$\Delta I = I - I_{x'} = -I_0 e^{-\mu_a x'}(1 - e^{-\mu_a (x - x')})$$

SYMBOLS

I = ionization current with material of thickness x, amperes

x = thickness in units of mass per unit area, mg/cm²

I_0 = ionization current with material of thickness 0 (in thickness measurements) or ionization current backscattered by the solvent when it contains no solute (in concentration measurements), amperes

ΔI = change in ionization current caused by material, amperes

μ_a = absorption coefficient, $(\text{mg/cm}^2)^{-1} = 0.693m/R_g$, empirically determined; due to scattering effects, it will show some dependence on the atomic number of the material being measured

R_g = maximum range of beta particles, mg/cm²
$= 412E^{1.265-0.220\log_{10}E}$ (when $E < 3$ Mev)
$= 542E - 133$ (when $E > 0.8$ Mev)

E = maximum energy beta emitted, Mev

m = a number from 6 to 13, depends on the geometry of the setup and on the beta particle energy spectrum characteristic of the source isotope

I_A = ionization current obtained for a saturation thickness of A

I_B = ionization current from B with zero thickness of A

μ_b = reflection coefficient, $(\text{mg/cm}^2)^{-1} = f\mu_a$ (empirically)

f = empirical factor
= 2.5 to 3

Z_A = effective atomic number of A

Z_B = effective atomic number of B

n = empirical exponent
= 0.7 to 0.8

x_s = saturation thickness, mg/cm²

K = a constant dependent on setup ($K \approx 4 \times 10^{-4}$ in author's experiments)

Z = effective atomic number of solute

Z_s = effective atomic number of solvent

c = concentration of solute dissolved in a low-atomic-number solvent (water or organic), weight per cent

j = empirical exponent ($j \approx 0.9_5$ in author's experiments)

k = empirical exponent ($k \approx 0.9_6$ in author's experiments)

M = meter reading, μa

R = load resistance from ionization chamber anode to ground, ohms

g_m = amplification = effective transconductance of electrometer tube amplifier system, μa/volt

S_x = sensitivity of thickness gage, μa/mg/cm²

S_c = sensitivity of concentration gage, μa/wt %

δx = uncertainty in thickness x

δc = uncertainty in concentration c

δM = uncertainty in meter reading

N = number of betas entering ionization chamber per second

C = capacity of ionization circuit, farads

q_{avg} = average charge produced by a beta particle in ionization chamber, coulombs/beta particle

σ_I = standard deviation of ionization current, I, through R

$(q^2)_{avg}^{1/2}$ = root-mean-square deviation of q

σ_M = standard deviation of meter reading due to statistical fluctuations

τ = equilibrium time, sec

Thickness-by-reflection. When a thin material, A, is laid over a thick material, B (usually thick enough to cause saturation backscattering from B), and beta particles backscatter into the ion chamber

$$\Delta I = I - I_B = (I_A - I_B)(1 - e^{-\mu_b x})$$

For saturation backscattering

$$\frac{I_A}{I_B} = \left(\frac{Z_A}{Z_B}\right)^n$$

and

$$\Delta I = I - I_B = I_B[(Z_A/Z_B)^n - 1](1 - e^{-\mu_b x})$$

Saturation thickness is

$$x_s \approx 116\, E^{0.67}$$

Concentration-by-reflection. When the beta particles received in the ionization chamber have been backscattered from a solution (liquid or solid) of at least saturation thickness

$$\Delta I = I - I_0 = I_0 K (Z - Z_s)^j c^k$$

where $Z_s < Z$

Accuracy

The usefulness of the gage is determined by the over-all accuracy with which measurements can be made.

As an example, assume that measurements are being made using a d-c electrometer bridge amplifier circuit with a d-c microammeter as the indicating meter. If the meter is zeroed for $\Delta I = 0$ and the polarity is such that a positive reading is obtained, then

$$M = |\Delta I R g_m|$$

Sensitivity. For each of the three types of gages, the sensitivity is

Thickness-by-transmission

$$S_x = \frac{dM}{dx} = I_0 R g_m \mu_a e^{-\mu_a x}$$

Thickness-by-reflection

$$S_x = \frac{dM}{dx} = |I_B R g_m[(Z_A/Z_B)^n - 1]\mu_b e^{-\mu_b x}|$$

Concentration-by-reflection

$$S_c = \frac{dM}{dc} = I_0 R g_m k K (Z - Z_s)^j c^{k-1}$$

Precision. Two factors influence the precision of measurement: (1) The uncertainty in the meter reading associated with its inherent accuracy; and, (2) The fluctuation in the meter due to statistical fluctuations in the number of beta particles and the

Calculated Characteristics of Three Types of Beta Gages

Type of Gage	ΔI (*amp*)	S_x ($\mu a/mg/cm^2$)	S_c (μa/wt. %)	$\delta x/x$	$\delta c/c$	σ_x/x	σ_c/c	τ (*sec*)
Thickness-by-transmission	1.72×10^{-10}	3.3	—	6.1×10^{-3}	—	1.6×10^{-3}	—	12.9
Thickness-by-reflection	1.85×10^{-10}	5.8	—	6.9×10^{-3}	—	1.9×10^{-3}	—	12.7
Concentration-by-reflection	4.8×10^{-11}	—	17.3	—	2.3×10^{-2}	—	0.66×10^{-2}	10.4

associated number of ion pairs (electric charge) that appear in the ionization chamber. The larger of the two factors determines the gage's over-all accuracy.

The accuracy of the measurement of thickness or concentration is related to the uncertainty in the meter reading by

$$\delta x = \frac{\delta M}{S_x} \quad \text{or} \quad \delta c = \frac{\delta M}{S_c}$$

In the case of a ratemeter-type circuit, the fractional standard deviation of the ionization current due to the random nature of radioactive decay is (*6*)

$$\frac{\sigma_I}{I} = \frac{1}{\sqrt{2NRC}} = \frac{1}{\sqrt{2IRC/q_{avg}}}$$

Since there is a statistical fluctuation in the charge produced by an individual beta particle, the expected fractional standard deviation of I is somewhat greater than that given above, and is

$$\frac{\sigma_I}{I} = \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right) \frac{1}{\sqrt{2IRC/q_{avg}}}$$

The standard deviation of the meter reading due to statistical fluctuations is

$$\sigma_M = \sigma_I R g_m = \frac{IRg_m}{\sqrt{2IRC/q_{avg}}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

The fractional standard deviations of thickness and concentration are

$$\frac{\sigma_x}{x} = \frac{\sigma_M}{xS_x} = \frac{g_m}{xS_x}\sqrt{\frac{IRq_{avg}}{2C}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

and

$$\frac{\sigma_c}{c} = \frac{g_m}{cS_c}\sqrt{\frac{IRq_{avg}}{2C}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

Over-all accuracy. In the determination of thickness and concentration with the three types of gages, the fractional uncertainties associated with inherent meter accuracy (δ's) and statistical fluctuations (σ's) of the radiation source are

Thickness-by-transmission

$$\frac{\delta x}{x} = \frac{\delta M}{xS_x} = \frac{e^{\mu_a x}\delta M}{\mu_a x I_0 R g_m}$$

$$\frac{\sigma_x}{x} = \frac{e^{\frac{1}{2}\mu_a x}}{\mu_a x\sqrt{2I_0RC/q_{avg}}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

Thickness-by-reflection

$$\frac{\delta x}{x} = \frac{e^{\mu_b x}\delta M}{\mu_b x I_B R g_m[(Z_A/Z_B)^n - 1]}$$

$$\frac{\sigma_x}{x} = \frac{e^{\mu_b x}\sqrt{(Z_A/Z_B)^n - [(Z_A/Z_B)^n - 1]e^{-\mu_b x}}}{\mu_b x[(Z_A/Z_B)^n - 1]\sqrt{2I_BRC/q_{avg}}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

Concentration-by-reflection

$$\frac{\delta c}{c} = \frac{\delta M}{I_0 R g_m k K (Z - Z_s)^j c^k}$$

$$\frac{\sigma_c}{c} = \frac{\sqrt{K(Z - Z_s)^j c^k + 1}}{kK(Z - Z_s)^j c^k \sqrt{2I_0RC/q_{avg}}} \left(\frac{\sqrt{(q^2)_{avg}}}{q_{avg}}\right)$$

The gross accuracy of measurement is determined principally by the larger of the two uncertainties. More precisely, the over-all fractional uncertainty is the root-mean-square value of the two fractional uncertainties. In general, the meter accuracy uncertainty is proportional to the source strength, the amplification, and the load resistance; but the source fluctuation uncertainty is inversely proportional to the square-root of both source strength and time constant RC. In an optimum design these variables would be chosen so that the two uncertainties are about equal.

Response Time

In the design of automatic controls that rely on beta-gage measurements, the gage's time of response is important. The equilibrium time for a rate meter to go from a rate of 0 to N particles per second is (*6*)

$$\tau = RC[\tfrac{1}{2} \ln (2NRC) + 0.394]$$

where τ is the time required for the exponentially decreasing difference between the actual and true counting rate reading to be less than the probable error due to statistical fluctuations.

It is, however, more rational to define equilibrium time in terms of the standard error rather than the probable error, and

$$\tau = \tfrac{1}{2} RC \ln (2NRC)$$

For thickness gage applications it is interesting to estimate the equilibrium time in going from counting rate N_1 to N_2 or ionization current I_1 to I_2. The equilibrium time (defined in terms of the standard error) in this case is

$$\tau = \frac{1}{2} RC \ln \left[\frac{2(N_2 - N_1)^2}{N_2} RC\right]$$

or

$$\tau = \frac{1}{2} RC \ln \left[\frac{2(I_2 - I_1)^2}{I_2} \frac{RC}{q_{avg}}\right]$$

It may be noted that τ is zero when

$$I_2 - I_1 = \sqrt{I_2/\sqrt{2RC}\ q_{avg}}$$

This occurs when the change in ionization current in going from I_1 to I_2 is equal to the standard deviation expected for an ionization current of magnitude I_2.

In terms of ΔI and I, where thickness or concentration changes from 0 to x or c, the equilibrium time is

$$\tau = 1.15\ RC \log_{10} \left[\frac{2(\Delta I)^2}{I} \frac{RC}{q_{avg}}\right]$$

One of the first steps in the design of a beta gage consists of choosing a time constant RC such that suitable equilibrium times are obtained for the changes in I involved in making the measurement of thickness or concentration.

Example

To illustrate the application of the quantitative relationships to the evaluation of an industrial beta gage, con-

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sider a series of uses where the gage is adapted to be a thickness-by-transmission gage, a thickness-by-reflection gage, and a concentration-by-reflection gage.

Equipment. The gage detector is a cylindrical ionization chamber with a thin stainless-steel window for beta-particle entry. The ionization current from the chamber is measured by a stable, one-stage, bridge-type d-c amplifier.

The very small ionization current ($\sim 2 \times 10^{-9}$) is put through a large resistance ($\sim 5 \times 10^{9}$ ohms) so the signal produced by the total source is 10 volts. This negative voltage is opposed by a positive voltage used for adjusting the operating point of the bridge circuit. The net sum of these voltages is applied to the grid of the electrometer tube as a signal in excess of its proper bias voltage. The electrometer tube forms one arm of a bridge (balanced when the proper bias voltage alone is applied to the electrometer tube). A variable sensitivity microammeter is set across the bridge to indicate any unbalance. The full-scale reading of the microammeter (at maximum sensitivity) is 20 μa, and the inherent "accuracy" of the meter, δM, is about 0.4 μa. The effective transconductance of the electrometer tube in the bridge circuit is about 80 μa/volt. The time constant of the gage is 2.0 sec.

The beta particles from strontium-90 of maximum energy 0.6 Mev are almost completely absorbed by the combination of absorbers comprising the stainless-steel source cover and the window of the ionization chamber. Therefore, the effective beta radiation from strontium-90 is actually that from its daughter, yttrium-90, which emits beta particles with a maximum energy of 2.2 Mev.

Coefficients. With this arrangement, it is found that for a

Thickness-by-transmission gage

$$\mu_a = 0.0045 \text{ (mg/cm}^2\text{)}^{-1}$$

Thickness-by-reflection gage

$$\mu_b = 0.012 \text{ (mg/cm}^2\text{)}^{-1}$$

Concentration-by-reflection gage

$$K = 4 \times 10^{-4}$$

Calculation. The table shows the characteristics calculated for three types of beta gages:

Thickness-by-transmission gage. Thickness measured is 20 mg/cm² and $I_0 = 2 \times 10^{-9}$ amps. Source $\approx$ 10 mc.

Thickness-by-reflection gage. A 10 mg/cm² piece of plastic ($Z_A \approx 5$) laid on a thick iron plate ($Z_B = 26$) is measured and $I_B = 2 \times 10^{-9}$ amps. Source $\approx$ 10 mc.

Concentration-by-reflection gage. A 1.0 weight per cent solution of lead ($Z = 82$) in water ($Z_s \approx 7$) is measured. $I_0 = 2 \times 10^{-9}$ amps. Source $\approx$ 20 mc.

A value of $q_{avg} = 1.6 \times 10^{-16}$ coulombs is estimated from a consideration of the ionization chamber geometry and data on the specific ionization of beta particles. It is assumed that $\sqrt{(q^2)_{avg}}$ is approximately equal to q_{avg}.

Certainty. From the table it can be seen that in each case, the "accuracy" of the meter, rather than the fluctuations due to the radioactive source, is the limiting factor in the measurements' uncertainty. Assuming that we do not to change the load resistor and thus the response characteristic of the gage, and assuming that it is impractical to use a more accurate microammeter, there remain two means for improving the certainty of measurement.

The first alternative involves increasing g_m by changing the electronic circuitry of the beta gage to form a more elaborate amplifier. An increase in amplification will not affect σ_x/x or σ_c/c. Thus the increase of g_m will be effective in decreasing the uncertainty only up to the point that σ_x/x or σ_c/c becomes larger than $\delta x/x$ or $\delta c/c$.

The second possibility entails increasing I_0 or I_B by increasing the strength of the source of beta radiation. The value of σ_x/x or σ_c/c will decrease in this case along with $\delta x/x$ or $\delta c/c$, but less rapidly because of their inverse square root and first power dependence, respectively, on ionization current.

* * *

The subject matter of this article constituted a portion of the lecture on Reflection Beta Gages presented on April 21, 1953, for the course "Advanced Radioisotope Techniques in Industry" sponsored by the Oak Ridge Institute of Nuclear Studies.

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LETTERS

Interpreting Wear Studies

DEAR SIR:

In the February, 1953, issue you published an article entitled "Wear Studies of Irradiated Carbide Cutting Tools" by L. G. Erwall and the undersigned. I have learned that certain of the published results have been misconstrued.

The purpose of the tests described was to determine if a simple relationship exists between the amount of carbide worn away from the *rake* and the time of machining at the cutting conditions reported in the article. However, estimates of the wear resistance of carbides usually refer to the breadth and the appearance of the wear land on the *clearance face* of the tool. These studies are made by means of a microscope at different times during the cutting process. Any general conclusions concerning tool lives of the two qualities of carbide used may therefore not be drawn from Fig. 5 of the article.

It is concluded from tests carried out after publication of the article that initial wear of carbide tips, i.e., the form of the material-transfer vs time curve during the first minutes of turning, is highly dependent upon how the cutting edge is ground. If, for instance, a rather large flat is stoned on the edge, the initial wear changes character and the wearing speed will eventually be constant even from the beginning of the machining operation. For tool quality 1, the stoned flat was smaller than that of quality 2.

Studies of wear on the *flank* by means of the radioactive techniques described in the article seemed to show that the wearing speed is constant here also.

—BERTIL COLDING
Inst. Mekanisk Teknologi
Kungl. Tekniska Högskolan
Stockholm, Sweden

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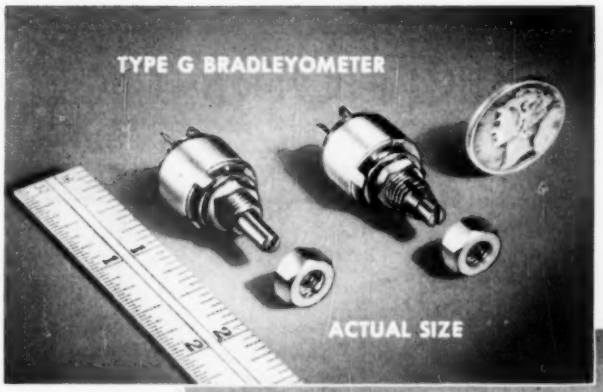

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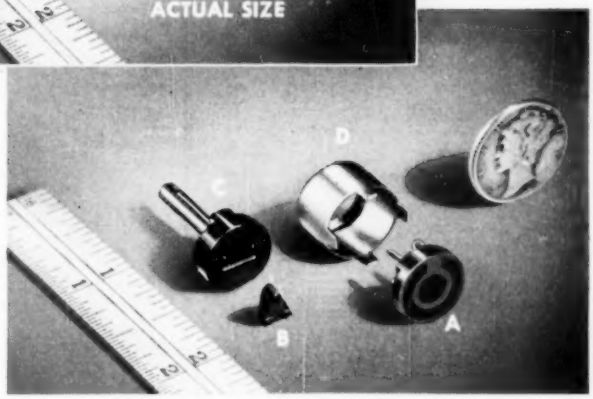

A—Resistor element molded in one piece with resistor and terminals. No rivets or welds.

B—Carbon brush.

C—Rotor and shaft showing opening for brush.

D—Metal case ½ inch in diameter.

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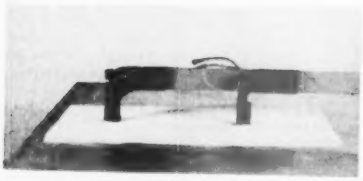
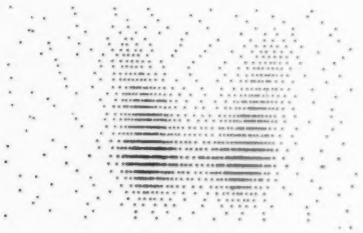


FIG. 1. Recording styli



Scale of 32

Scale of 64

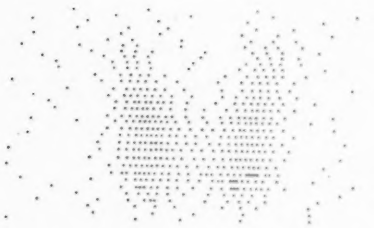


FIG. 2. Gammagraph of thyroid phantom

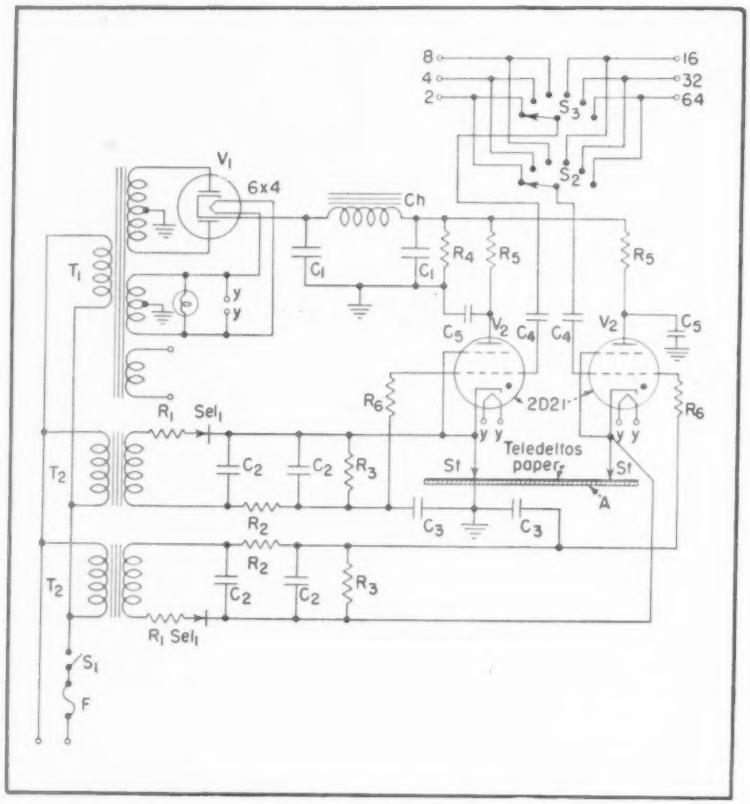


FIG. 3. Recorder circuit. *St* denotes stylus; *A*, the scintiscanner moving drawing table

Electric Recorder for the Gammagraph

By MARTIN E. JACOBS, ALAN L. ORVIS, and BERNICE B. BORRMAN
Section of Biophysics and Biophysical Research
Mayo Clinic, Rochester, Minnesota

The conventional gammagraph* uses a recording system consisting of an electromagnet, a stylus, and a drawing table. By placing tracing paper and carbon paper between the stylus and the drawing table, the distribution of radioactivity in an area being scanned is recorded.

We have noted two disadvantages in this system:

1. The noise associated with this type of recorder is annoying to patients, especially in cases of hyperthyroidism.

2. Blackness of the individual traces recorded is dependent upon the counting rates, since the arc of excursion of the stylus is reduced at the higher counting rates when the time interval between successive pulses is less than the time required for the stylus to return to its resting position. This latter effect tends to create a false impression of the distribution of the radioactivity on the record.

An electric recorder has been developed that eliminates recorder noise and produces traces of uniform quality. A single unit consists essentially of a thyratron switch tube, a capacitor, a stylus electrode, and the associated power supply.

An electric connection is made to

* B. Cassen *et al.* Instrumentation for I^{131} use in medical studies, NUCLEONICS **9**, No. 2, 46 (1951).

the scale selector switch of the scaler. The pulse that triggers the scaler mechanical-register switch tube (6V6) triggers the thyratron and causes the storage capacitor (connected between the anode of the thyratron and ground) to discharge through the stylus. In passing from the stylus to the grounded aluminum drawing table, the charge passes through Western Union Teledeltos recording paper, type L-39. The resulting trace has much the same shape as the cross-section of the stylus electrode. A stylus with a circular cross section and diameter of 1 mm has given satisfactory recordings.

The system now being used employs duplicate styli fed by separate thyratrons and storage capacitors. The inputs have independent selector switches, enabling the operator to choose the same or different scaling factors for each stylus. Thus duplicate records may be obtained on one sheet of Teledeltos paper, or two records with different scaling factors can be made instead. This latter feature often enhances interpretation when details of the two records are compared.

The recorder is shown in Fig. 1. The machined brass styli are fitted into Bakelite guides for lateral support and for insulation from the horizontal supporting arm. The styli are free to move vertically to insure contact with the Teledeltos paper during the scanning procedure. Spring clips between the guides and the drawing table keep the Teledeltos paper flat, and insure good electric contact between the paper and the drawing table.

Figure 2 shows a typical gammagraph of a thyroid phantom taken with scaling factors of 32 and 64. The electric circuit is shown in Fig. 3.

The electric components have been chosen so that the speed of response of the recording system is adequate to cause an overlapping of dots at maximal scanning speed when the counting rate taken from the scaler is chosen sufficiently high. Also, the time constant of the charging system is small enough so that the quality of the individual traces is independent of their rate of repetition over the range of counting rates encountered with the gammagraph.

This recording system has been operating satisfactorily for the past several months.

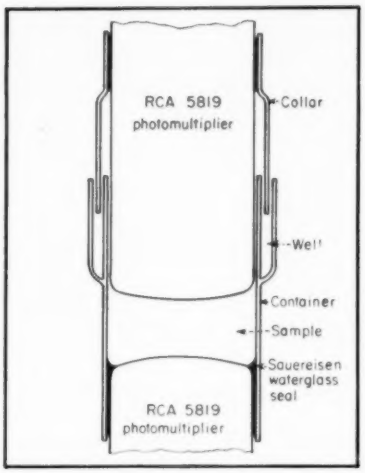


FIG. 1. Overlapping beakers prevent evaporation of liquid phosphor during long counting periods

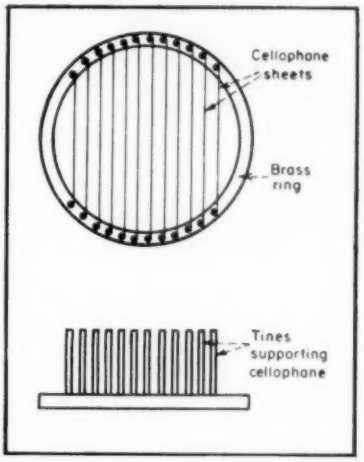


FIG. 2. Strip holder used to support cellophane sample strips perpendicular to photocathodes

Solid-Sample Beta Determinations with a Liquid Scintillation Counter

By F. TERENTIUK*
Physics Department
University of British Columbia
Vancouver, Canada

In the liquid scintillation counter for beta-ray activity measurements, described last year,† solid samples are immersed in a liquid phosphor and the light flashes counted simultaneously with the help of two photomultiplier tubes in a coincidence circuit. The counter operates not only with high efficiency, but allows the determination of very low specific activities by virtue of the fact that large amounts of solid material can be used, namely of the order 50 grams in the "volume counter."

The purpose of this note is to report on the practical development of the counter and the limits of sensitivity observed.

1. To prevent evaporation of the liquid phosphor during long counting periods, the sample is kept in a closed compartment formed by two glass beakers cemented to the photomultipliers, as shown in Fig. 1. The upper beaker fits into the double-walled space of the lower beaker, which can be filled with liquid phosphor, or pure toluene, or mercury. The beakers are silvered on the inside.

2. In counting beta particles of low energy, the disturbing background due to high-energy cosmic radiations has been reduced through the introduction of an anticoincidence discriminator that quenches simultaneous pulses greater than those of a certain maximum value. In this way the background count has been reduced in C^{14} determinations by about one-third to 0.7 counts per second, using the same—not quite adequate—iron and lead shielding that was used previously.

3. Various measurements were made to test the sensitivity of the volume counter both for high-energy (K^{40}) and low-energy beta particles (S^{35}, C^{14}). The active material was present in the form of transparent crystalline powders mixed into a paste with the liquid phosphor (potassium chloride, potassium nitrate; sodium sulphate; ammonium carbonate, urea, dextrose). The specific activities measurable in short counting times (30 min) were

* Present Address: Applied Physics Division, National Research Council, Ottawa, Ontario, Canada.

† O. Blüh, F. Terentiuk, Nucleonics **10**, No. 9, 48 (1952).

found to be: for high-energy beta particles, 10^{-11} curies/gm; for low-energy beta particles 10^{-10} curies/gm. With the same method of sample preparation, the reproducibility of results showed variations not greater than 2%. The efficiency of counting C^{14} was found to be considerably higher than had been reported before, namely about 20%. The earlier value of about 1% was obtained with material whose activity had been overestimated.

4. In the multiple-sample counter the solid material was previously deposited on cellophane strips oriented parallel to the photocathodes. In a new arrangement the strips are placed vertically to the end-faces of the multiplier tubes. The circular strip-holder (Fig. 2) carries a number of tines to which the cellophane films can be cemented. With this type mount, C^{14} could be counted with an efficiency of up to 40%. The arrangement has the further advantage that it can be used for nontransparent samples, e.g., filter paper (as used in chromatography), or metal strips with electrolytic radioactive deposits.

* * *

Financial support for this work was made available through a research grant from the Canadian National Research Council to Dr. Otto Blüh. I am indebted to Professor Blüh for his advice and encouragement, and to Drs. E. K. Darby and G. W. Williams for assistance in connection with the electronics work.

FIG. 1. Face mask used for charcoal adsorption of breath radon

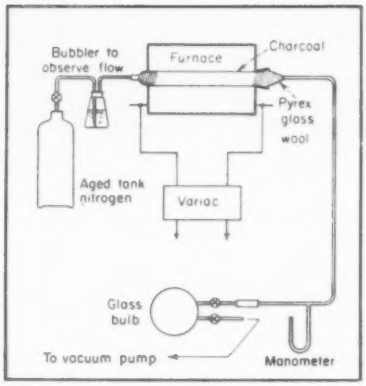


FIG. 2. Apparatus for freeing radon from charcoal by heating

Measurement of Breath Radon by Charcoal Adsorption

By JOHN B. HURSH
Atomic Energy Project
University of Rochester
Rochester, New York

Use of activated charcoal for collecting breath radon and concentrating it about 30-fold for subsequent measurement avoids some of the difficulties inherent in the air-bulb technique currently used to estimate body radium content in humans. The adsorbed radon is collected for measurement by heating the charcoal.

The method in general use is to collect a breath sample in a 1-liter glass bulb that is then sealed and shipped to a laboratory where the liter of expired air is analyzed for radon. As a routine procedure it suffers two disadvantages:

1. Measurement in the range of 0.3–0.5 $\mu\mu c$ is required. Great care is

(Continued on next page)

Go, No-Go Radiation Detector

By H. D. LeVINE
New York Operations Office
U. S. Atomic Energy Commission
New York, New York

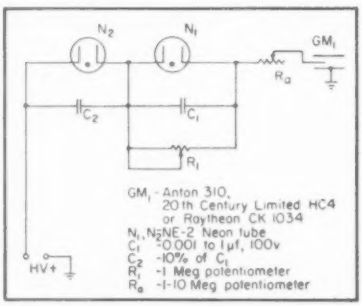
There has been an unfilled need for a simple circuit that would allow the fabrication of an inexpensive go, no-go radiation detector that would be useful for disaster purposes where residual gamma radiation is present.

The circuit shown on this page is a basic Geiger integrator circuit that uses one or more neon bulbs as indicating elements. Although all commercial neon bulbs do not fire at a specific voltage, the characteristics of the circuit can be adjusted so that any neon bulb will operate at a predetermined radiation flux. The anode series resistor, R_a, will effectively control the charge per pulse of the Geiger tube and therefore the voltage that will appear at capacitor C_1, which is proportional to the number of pulses and charge per pulse. The resistor R_1* shunting C_1 controls the rate of leakage of charge from C_1. Unless the input current from the Geiger tube is adequate, the firing voltage of the neon tube N_1 will not be reached. The indicator is therefore quiescent until a specific radiation level is reached.

The circuit in the illustration provides three degrees of indication. C_1 is about 10 times larger than C_2, so that the voltage across C_1 will increase 10 times more rapidly than the voltage across C_2. N_1 and N_2 will then fire at radiation levels inversely proportional to the capacitance of C_1 and C_2.

An instrument has been built, incorporating this circuit, that indicates less than 1 r/hr, more than 1 but less than 10 r/hr, and above 10 r/hr by no lights, one light, and two lights lit respectively.

This battery-powered unit could be left on continuously since current drain is negligible at low radiation levels. The shelf life of the batteries would control the battery replacement rate. It should also be possible to use a simple vibrator power supply.*



THREE-RANGE go, no-go Geiger integrator

* For example, the Vitran described in NYO-1538, page 35.

needed to avoid sample contamination.

2. An air sample that is representative of the tidal air of the subject is difficult to collect. Variations in breathing can cause divergent results.

Procedure with Charcoal

In outline, the procedure consists of fitting the subject with a face mask having a charcoal-filled cartridge on both the valved air outflow and inflow. The subject breathes through the mask for a measured period of time. In the laboratory, the charcoal is transferred to an ignition tube and radon released by heating in a nitrogen atmosphere.

Radon collection. The face mask shown in Fig. 1 was adapted from a commercial type manufactured by the Pulmosan Co. The canisters contain 90 gm of 8–12 mesh activated coconut charcoal (without zinc compounds that impede release of adsorbed radon) obtained from Barneby-Cheney Engineering Co. When not in use, the canisters are stored in individual close-fitting sealed Lucite containers. The charcoal in a cartridge has been reused for a dozen runs with no deterioration; maximum re-use was not determined.

In collection, the customary precautions are observed to minimize the effect of radon present in the inspired air. The subject is tested at a laboratory outside the plant, and it is stipulated that he shall have been absent from the plant for at least 12 hours (48 hours if plant atmosphere contains $> 10\ \mu\mu c$/liter of radon).

The subject sits at rest for 10 min with the mask in place and a charcoal cartridge on the inspiration vent. A cartridge is then placed on the expiration vent and radon collected for a selected time (5–10 min). An integrating gas flow-meter can be used to measure total expired air if results are to be reported in $\mu\mu c$/liter. At the conclusion of the measurement period the charcoal cartridge on the expired air side is immediately transferred to its Lucite container and sealed.

Release of adsorbed radon. To release the radon, the charcoal is transferred to the Pyrex tube of the apparatus shown in Fig. 2. The entire system is evacuated, and the charcoal tube introduced into a furnace preheated to 350° C air temperature at the middle of the tubular space. A controlled flow of nitrogen is swept through the charcoal tube at a rate such that after 15 min the collection bulb is filled to atmospheric pressure.

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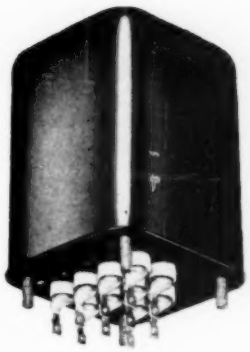

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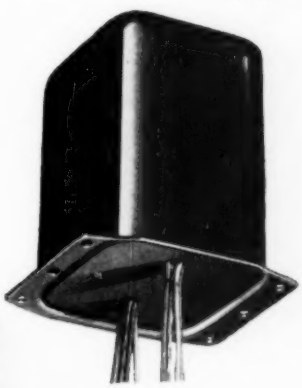

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is then removed from the system; the gas containing radon is transferred into the chamber of the alpha counter by displacing it with water. An additional liter of compressed air (aged at least 3 months) is added to the chamber to flush radon in the traps and bring the chamber to atmospheric pressure.

Measurement. The 2-liter chamber used for measurements* is operated with the central collecting rod at ground and the chamber wall at +1,500 volts. Thus positive ions are collected; this provides a sloppy pulse and limited counting rates, but oxygen need not be removed from counting gas.

Recoveries and Blanks

Recovery of breath radon by this procedure was examined with an artificial lung and spirometer. A known sample of radon from a RaCl standard was introduced into the spirometer, which was filled to 30 liters with expired air that had been stripped of radon by passing it through a charcoal cartridge. A small fan in the spirometer mixed the gas thoroughly.

The artificial lung—a valved rubber balloon in the spirometer exhaust that was inflated and deflated by the operator breathing into the bottle surrounding the balloon—was used to pass the spirometer air through a charcoal cartridge at a rate approximating the normal breathing rate of man. The total time to "expire" the 30-liter volume varied from 5.5 to 6.0 min.

The radon adsorbed on the charcoal was released and measured by the methods described previously. Results of 21 runs indicate that recovery is satisfactory (85–100.5%). A tendency toward somewhat lower recoveries as the sample increased from 0.20 to 12.3 $\mu\mu c$/liter of radon was noted.

With no radon added to the spirometer, small significant amounts of radon were measured in gas samples collected from the heated charcoal. This was attributed to radium contained in the charcoal; measurements made after radon had been allowed to accumulate indicated that the charcoal had an equivalent radium content of about 3.3×10^{-14} curies/gm. This value was used to correct results.

Field Measurements

Two charcoal-cartridge measurements, separated by $6\frac{1}{2}$ months, have been made on each of three radium

*J. B. Hursh, A. A. Gates, NUCLEONICS 7, No. 1, 46 (1950).

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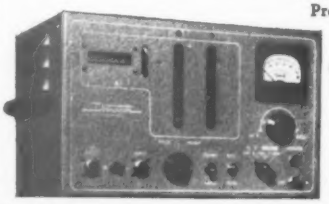

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plant workers whose radium content had been monitored periodically by the routine breath-bulb technique. The following results, in $\mu\mu c$/liter radon were obtained in the two tests for each worker: 3.90 and 3.10; 8.60 and 8.45; 0.75 and 0.85. The last two measurements by the breath-bulb technique, just prior to the first charcoal-cartridge test, were, respectively: 3.90 and 5.53; 10.4 and 4.46; 1.67 and 2.26. The variations for each worker do not correlate with his job history.

These limited results provide only slight confirmation of the usefulness of the charcoal cartridge for field measurements.

Discussion

The charcoal adsorption method of radon collection uses a prolonged sampling period that provides a sample higher in activity and more physiologically adequate, compared to the breath-bulb technique. Activity of the sample is increased 30–50 times, and the background contribution of the radium content of the charcoal can be determined quite accurately. While the breath-bulb technique provides a measureable sample, the larger charcoal-cartridge sample makes measurement possible in a shorter time. Where availability of measuring equipment is a problem, this could be a real advantage.

It might appear that the increase in respiratory dead space brought about by use of a face mask was a disadvantage of the charcoal cartridge method. However, the human body responds to the increase in dead space by a prompt increase in ventilation rate so that the initial 10-min breathing period with the mask in place serves to stabilize the rate of radon loss.

A sampling problem common to both methods is that the body, even with a negligible radium burden, comes into equilibrium with the radon in the surrounding air. This problem is surmounted by sampling after the worker has been in a "radon-free" atmosphere for an extended time. Calculations indicate that the amounts of plant-air radon are negligible after the worker has been out of the plant for 48 hr or more. However, no environment is entirely radon-free. But the error caused by normal low levels of radon is made negligible by the 10-min breathing of "radon-stripped" air before the charcoal-cartridge measurement is made.

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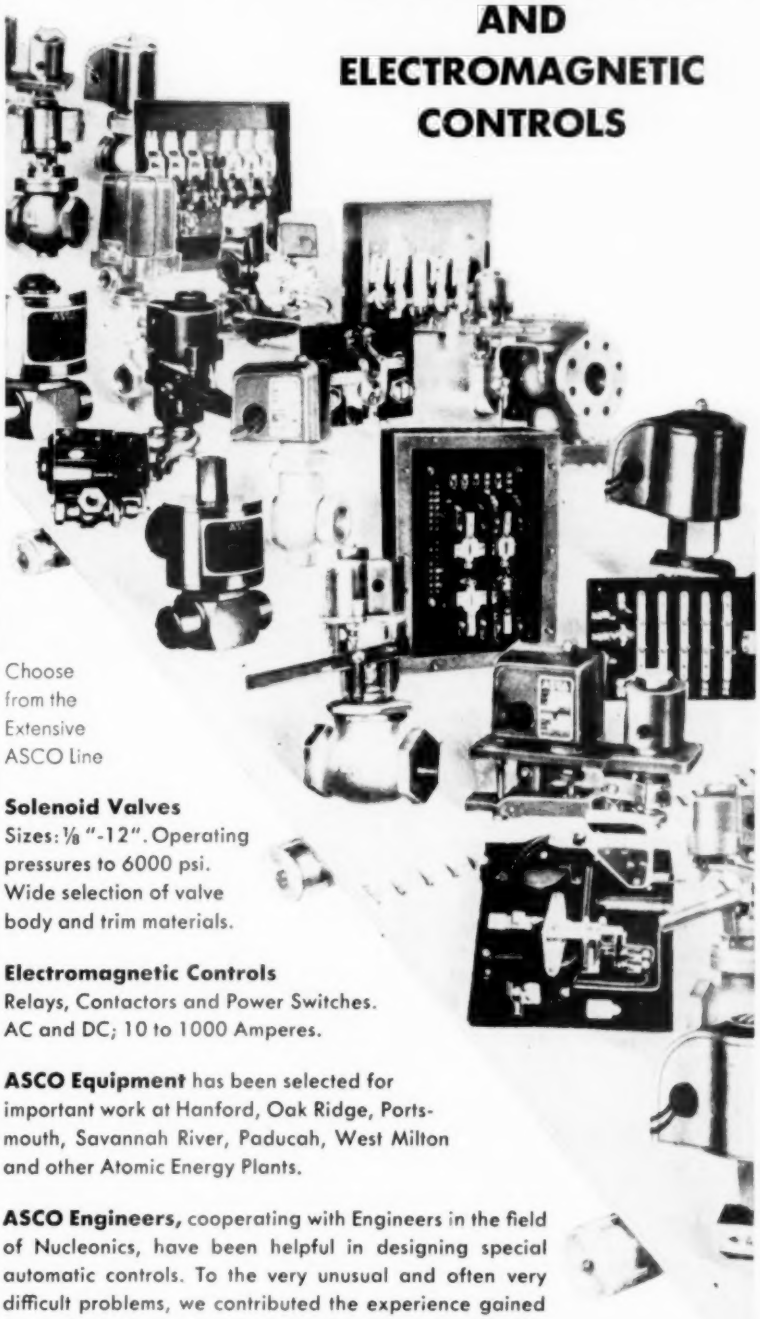

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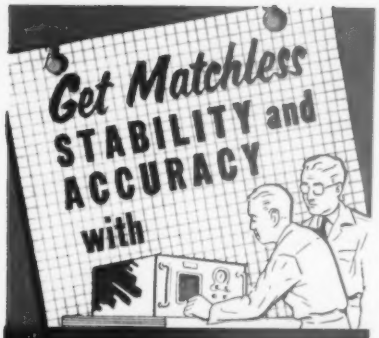

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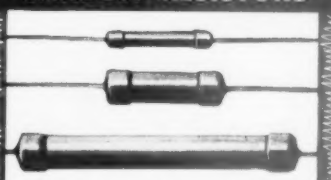

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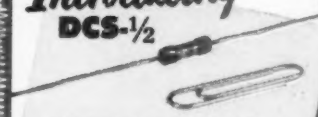

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Reactor Designs for Commercial Power

By J. R. MENKE
Nuclear Development Associates, Inc.
White Plains, New York

A variety of reactor types are being considered in an effort to solve the design problems of commercial nuclear power plants.

A set of reactor "profiles" indicates the complexity of the choice facing the reactor designer. The illustration shows how five types of reactors rate in regard to the five main problems. Many other types of reactors and problems could be considered; however, the ones mentioned here cover a large portion of the possibilities.

Individual designers are not equally impressed by the importance of each problem. Hence, it is not reasonable simply to add the "ratings" of each reactor to arrive at a significant total rating. An integrating effect will eventually lead to a choice.

The graphite-moderated reactor, as typified by the Hanford design, is one that rates poor in neutron economy. It also rates poor in processing because of its multitude of solid fuel rods, which are difficult and expensive to fabricate and handle. It rates intermediate in capital cost, poor in expected revenue and intermediate in safety. However, this reactor is certainly one for which design, construction, and operating experience are relatively plentiful. It must, therefore, be rated as presenting little construction difficulty. Here, then, is a reactor that most certainly can be built, but it holds little promise of being economic over the long term.

The heavy-water-moderated reactor, similar to the Norwegian, Argonne, and Canadian reactors, rates intermediate in neutron economy and poor in processing—again because of the solid, hard-to-fabricate fuel elements. It rates poor on capital cost because of the large investment required for heavy water. It rates intermediate in both revenue and safety. Enough is known about this type to make it capable of early construction.

The light-water-moderated reactor rates poor in neutron economy and poor in ease of reprocessing. Its capital cost should be intermediate, revenue poor, and its safety intermediate. It can probably be built immediately.

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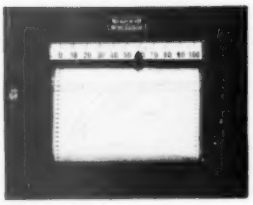

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in neutron economy but best in processing and capital cost. It should be intermediate in both revenue and safety. Since a pilot model has been operated, this reactor rates intermediate in the scale of difficulty. It is a very attractive approach to the problem.

The fast reactor, as typified by the EBR, rates very high in neutron economy and revenue. Unfortunately, it now rates poor in processing. Little is known concerning its safety. The fast reactor's ultimate fate is likely to depend on the requisite capital investment, which is as yet undetermined. Should the cost be favorable, there will be much to say for this reactor. Should it be unfavorable, it may be difficult to justify the construction of this type of reactor on purely economic grounds. It is the current aim of at least one of the industrial study groups to determine the capital cost characteristic of fast, dual-purpose reactors.

* * *

This article is based on a talk before the National Industrial Conference Board, New York, October 19, 1953.

Survey of Radioactive-Waste Disposal Practices

By H. S. MILLER,
F. FAHNOE, and
W. R. PETERSON
Vitro Corporation of America
New York, New York

TABLE 1 Questionnaire Distribution and Response

Type of establishment	*Questionnaire Sent (no.)*	*Replies (no.)*	*Replies (%)*
Governmental	126	90	71.4
Medical and health	130	75	57.8
Industrial	387	248	64.1
Research	36	25	69.4
Educational	348	243	69.8
	TOTAL 1,027	681	Avg 66.3

TABLE 2 Questionnaire on Radioactive-Waste Disposal Practices

Question	*Alternatives*	*Replies (no.)*	*Replies (% / question)*
1. Wastes are:	(a) aqueous liquids	357	50
	(b) non-aqueous liquids	73	10
	(c) solids	284	40
2. Solids are:	(a) water-soluble	238	48
	(b) not water-soluble	256	52
3. Quantity of wastes (gal/day):	(a) less than 2	379	92
	(b) about 5	21	5
	(c) 10 or more	10	3
4. Liquid wastes have:	(a) less than 1 μc/gal	241	60
	(b) about 100 μc/gal	127	31
	(c) 1 mc/gal or more	38	9
5. Concentration of inactive salts in the waste:	(a) less than 10 ppm	126	30
	(b) about 100 ppm	105	29
	(c) 1,000 ppm or more	128	36
6. Methods of disposal:	(a) dilution and discharge to sewer	282	41
	(b) storage and decay	273	40
	(c) bulk removal and dumping	126	19
7. Approximate cost of disposal:	(a) no expense	171	56
	(b) negligible	38	13
	(c) $1 to $6,000/yr.	94	31
8. Have discussed disposal with a non-AEC agency:	(a) yes	92	21
	(b) no	344	79
9. Method discussed:	(a) removal of liquid wastes by agency	43	56
	(b) evaporation and removal of residue	18	24
	(c) removal of active matter on solid adsorbent	15	20
10. Believe existing methods present a hazard with increased use of isotopes:	(a) yes	116	28
	(b) no	300	72

Progressive health agencies have become concerned about the lack of uniformity in radioactive-waste disposal practices (*1*). In the interest of protecting the public from potential hazards, the Atomic Energy Commission requested Vitro Corporation to conduct a survey to determine disposal practices, problems, and costs.

In December, 1952, a questionnaire was sent to 1,027 users (*2*) of radioisotopes. A breakdown of distribution is shown in Table 1. A general summary of answers is presented in Table 2.

The survey indicates a wide variation in usage of isotopes and an equally broad disposal problem.

One of the most important survey findings was that about 41% of the users disposed of radioactive wastes by dilution and discharge into sewers. Although this may not be a hazardous procedure at present (owing to the limited quantities of isotopes currently in use), the procedure is not a wise one and should be discouraged.

Two-hundred-nine installations had negligible radioactive-waste disposal expenses; 24 spent $1 to $25 per year; 16 spent $25 to $50 per year; 18 spent $50 to $100 per year; 26 spent $100 to $500 per year; 5 spent $500 to $1,000 per year; and 5 spent $1,000 to $6,000 per year.

BIBLIOGRAPHY

1. *Atomic Energy Newsletter* (Nov. 6, 1951)
2. "Isotopes—A Five-Year Summary of Distribution" (U. S. Atomic Energy Commission, Washington, D. C., 1951)

REACTOR FACTS

• **"Clementine,"** the recently dismantled fast reactor at Los Alamos, held three world firsts—first reactor to use pure fissionable material, first to use liquid metal (mercury) as the coolant, and first not to use a moderator.

• **EBR** is expected ultimately to run on plutonium just as well as on U^{235}.

• **Cost of HRE** was $1,000,000; it took about $3,000,000 to develop.

• **SIR moderator** will be beryllium.

• **STR-prototype** in Idaho cost $20-million, exclusive of fuel.

• **A gaseous diffusion plant** can be built slightly faster than the power plant for it.

• **British pilot nuclear power plant** at Cumberland is being planned for operating temperatures of 350 to 400° C. At these temperatures, aluminum or magnesium can be used to can fuel. With carbon dioxide as the heat transfer medium, designers hope to achieve thermodynamic efficiencies of 20 to 25%. Planned 40,000-kw power is half that of average generating station now in use in Britain.

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BOOKS

Luminescence and the Scintillation Counter

By S. C. CURRAN (Academic Press, Inc., New York, and Butterworth's Scientific Publications, London, 1953, x + 219 pages, $5.80). Reviewed by P. R. BELL, Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Dr. Curran's book is written as a guide to the subject of the scintillation counter. As he points out, the scintillation counter is an exceedingly flexible device and despite its recent appearance has already displaced other detectors in many fields of measurement.

All of the subjects relating to the scintillation counter problem are discussed with special emphasis upon the mechanism of the fluorescence process in solids and liquids and upon the secondary emission process involved in the photomultiplier.

The chapter on secondary emission includes an excellent list of references and a discussion of emission by both electron and positive ion bombardment.

The considerable amount of information about the various types of photomultipliers and the actual performance of commercially available models will be of great assistance to those trying to use scintillation counters in measurement. An experimenter who has read this book will not be unpleasantly surprised by an unanticipated effect from an external magnetic field on the counters or by the delayed after-pulses in the multiplier.

The various modes of interaction of radiation with the material of the phosphor are outlined in Chapter 2. These interactions lead to the complex pulse distributions observed at the output of a scintillation counter. Some examples of the various types of pulse distribution are analyzed in the section on applications of scintillation counters.

The section of the book dealing with the mechanism of fluorescence in solids and liquids presents the various theories so far put forward to explain both the fluorescent efficiencies observed and the change of light pulse output observed for various types of ionizing particles of different energy. The practical preparation of scintillation phosphors is described and reference to the principal papers is given.

So rapid is the development of new scintillation phosphors that considerable material, especially on the plastic phosphors, has appeared since the book went to press. The reference list extends well into 1952, however. The properties of many scintillation media are summarized in tables and graphs so that a choice of a phosphor is considerably assisted.

The last three chapters of the book are an outline of the use of scintillation counters and electron multipliers for the measurement of radiation and examples of the circuit arrangements needed for scintillation counters, coincidence circuits, and pulse-height-analysis equipment.

Among the various types of counter arrangement described are: counter telescopes for high-energy particles; single, split crystal and internal source arrangements for beta rays; single, double and triple crystal spectrometers for gamma rays and various arrangements for fast neutron spectrometry.

Circuit diagrams of some of the coincidence counting arrangements with short resolving time are shown, and their performance is discussed. This is followed by an outline of most of the types of pulse-height analyzers (kick-sorters) in general use. This section of the book is all too short. In the reviewer's opinion, the failings of an experimental system can often be traced not to a failure of the method, but to the shortcomings of the electronic equipment used.

Anyone intending to use scintillation counters in his research will find this book an excellent and timely source of information and references.

BOOKS RECEIVED

Complex Variable Theory and Transform Calculus, by N. W. McLachlan, Cambridge University Press, New York, 1953, xi + 388 pages, $10.00. This is the second edition of the book first published in 1939 as "Complex Variable and Operational Calculus with Technical Applications." Still written for the technologist, new subject matter added includes repeated impulses, Fourier transforms, and frequency spectra.

Simultaneous Linear Equations and the Determination of Eigenvalues, edited by L. J. Paige and Olga Taussky, National Bureau of Standards Applied Mathematics Series 29, Government

Printing Office, Washington 25, D. C., 1953. 126 pages, $1.50. This volume contains a majority (19) of the papers presented at a symposium held at the NBS Institute for Numerical Analysis at Los Angeles, August, 1951.

Roger Bacon in Life and Legend, by E. Westacott, Philosophical Library, New York, 1953, xii + 140 pages, $3.75. This biography presents a rather complete picture of the many-sided character of this pioneer of science.

ALSO OF NOTE

The Meaning of the 1953 Hearings on Atomic Energy. This report of the first activity of the Atomic Industrial Forum presents the minutes of a panel discussion held November 19. The ten panel members included representatives of government, labor, industry, universities, and the legal profession. Topics of discussion were: the need for atomic power, the state of the technology, steps necessary to develop atomic power, regulatory powers of government, patent rights, safeguarding the public interest, ownership of fuels and facilities, secrecy and the government's role in research, the "giveaway" question, other-than-power possibilities, and willingness of industry to invest. *The Atomic Industrial Forum Inc., 260 Madison Ave., New York 16, N. Y., $1.00.*

Metallurgy and Ceramics. This bibliography of selected unclassified AEC reports, TID-3050, includes 219 references of interest to industries in the metallurgical and ceramic fields. *Industrial Information Branch, Atomic Energy Commission, Washington 25, D. C.*

Laboratory Experiments with Radioisotopes for High School Science Demonstrations. This booklet details 20 experiments and explains how nuclear radiations are detected and measured. The experiments are based on lectures and experiments given in a course for high school teachers in 1952 by the Board of Education of the City of New York. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.25.*

Electrochemical Constants. NBS Circular 524 contains 30 papers presented at the National Bureau of Standards Semicentennial Symposium on Electrochemical Constants, Sept. 19, 1951. *Government Printing Office, Washington 25, D. C., $2.00.*

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NEWS

Eisenhower Proposes International Agency for Developing Peacetime Applications of Atomic Energy

A major step in the direction of exploitation of peacetime uses of atomic energy was made by President Eisenhower last month. In pointing out the need of the world to push weapons into the background and civilian applications into the forefront, he proposed an international cooperative effort for this purpose.

Although there are numerous problems involved in the setting up of such an effort, it is felt that the idea is the most constructive one put forth in recent years. The main problems are:

1. Exchange of sensitive information.

2. Control of uranium and fissionable material produced in any reactors involved.

The proposal envisions a modest beginning. President Eisenhower, in his December 8th speech before the United Nations General Assembly, gave at least three hints of the limited initial objectives of such an organization:

1. He spoke of material contributions at first that would be "small in quantity."

2. These contributions, he continued, would be from national stockpiles of "normal uranium and fissionable materials. . . ."

3. He put nuclear power development by the international agency in a "special purpose" category, with initial attention being given to application of "atomic energy to the needs of agriculture, medicine and other peaceful activities."

It is obvious that the activities of such an agency, should it come into being, would be limited by the amount of information and material it had to work with. Because of political, legal, and scientific implications, initial material contributions to the agency would probably be token amounts.

The President's phrasing of "normal uranium and fissionable materials . . . " may sound redundant, but the demarkation is clearer in light of the Atomic Energy Act. Under the Act, the U. S. is specifically prohibited from exporting or allowing private ownership of fissionable material. The law is less strict on ownership or export of "source materials," which include natural uranium and thorium.

By speaking of them separately, Mr. Eisenhower or his advisors may very well have had in mind the contribution of "source material" to the international agency before extensive changes in the basic law are undertaken.

Again under the law, the U. S. is specifically prohibited from exchanging information on development of industrial nuclear power without prior Congressional approval. This may explain why the President chose to deal with the nuclear power aspect separately from the medical and agricultural uses for fissionable material. There is already a considerable amount of declassified material on the use of radioisotopes in medical and agricultural research.

Some observers believe that an international agency might get a modest start with declassified information from the U. S. and other countries. As far as the U. S. is concerned, it would be able to contribute small amounts of "normal" uranium and thorium with little or no change in the Atomic Energy Act.

Thus far, Russia's main contribution to public information in the nuclear field has been confined to isotopes. Under the limited objectives contemplated for initiating the international agency, Russia would be eligible to participate and contribute declassified and some "source material."

These limited objectives have the virtue of offering an avenue toward wider exchange of information on peaceful uses of nuclear technology, while avoiding an immediate showdown on more sensitive data.

It is likely that the U. S., Russia, and Great Britain—the leaders in nuclear technology—have, or think they have, sufficient intelligence on the existing atomic stockpiles to set ratios for initial contributions. In any event, the initial contributions would be so small as to be negligible from the military standpoint.

If the international agency ever grew to the point that it could use sizeable contributions of either source or fissionable material, the actual size of national atomic stockpiles would become important.

But before that point was reached, the agency would have to clear another hurdle—that of obtaining information on reactors for producing electric power. Full U. S. participation in this phase of exchange would require revision of existing law.

Before the U. S. Government starts sharing atomic power information with other nations, it will certainly want a trial run at home. This would mean revisions in the Atomic Energy Act to permit wider industrial participation in nuclear power development. One immediate effect of the Eisenhower proposal may be more administrative emphasis on these revisions.

Bar, Electrical Groups Suggest Law Changes

Both the American Bar Association and the Edison Electric Institute have recommended in detailed proposals that the Atomic Energy Act be revised to permit industry to own, lease, use and sell fissionable materials and power reactors.

The Bar Association also recommended that revisions be made to permit industry to safeguard its inventions by the normal patent process. If an initial period of compulsory licensing of patents that might be considered restrictive is felt necessary, it should not be continued beyond 1960.

The recommendations were made at the request of the Joint Congressional Committee on Atomic Energy.

Canadian Agency Invests in Nuclear-Power Study

The Hydro-Electric Power Commission of Ontario is investing $200,000 in a two-year feasibility study of nuclear power. If the results are promising, a power reactor may be constructed by the agency near Chalk River. The power produced would be fed into the Ontario power grid.

The Canadian government, which operates the research establishment at

Chalk River, believes that organizations producing and distributing power should develop nuclear plants (NU, Aug. '53, p. 64). With this in view, several senior officials of provincial agencies (including Ontario Hydro) and privately-owned power companies have been appointed to the board of Atomic Energy of Canada Limited, the federal government's Chalk River operating agency.

Dutch Plan Experimental Nuclear Power Station

Within five to eight years, an experimental nuclear power station will be built near Nymegen, Netherlands. As planned, it will initially generate 100,000 kw on a commercial basis. Cost-price is expected to approximate that of coal-produced electricity.

F. O. M., the Dutch institution for fundamental materials research, and K. E. N. A., an electricity research center, are backing the plan.

3 Nations Will Release More Power-Reactor Data

Release of additional information on power reactors and related materials technology has been approved by the U. S. Atomic Energy Commission and the governments of Canada and the United Kingdom.

Revisions in the Tripartite Declassification Guide, recommended at an international conference held in Canada last April, were approved by AEC in November. The action permits the release of specified technical information shared by the three countries as a result of their combined wartime efforts.

Release of specific reports will clarify the extent of declassification agreed to. However, some of the items to be released involve: Certain data on uranium and slightly-enriched power reactors, certain physical properties of pure metallic plutonium, fluoride surface chemistry, and the spontaneous fission rates for Pu^{240} and U^{236}.

A joint statement on the action by the three countries is expected in January.

Planning Progresses for European Research Center

Nuclear scientists from 12 European nations met in Geneva last November for the 7th session of the European

Washington Report

▶REVISION OF ATOMIC ENERGY ACT will compete with other legislation of national significance for attention of Congress. Election-year atmosphere and relatively short session could make the going tough.

Changes in the law to permit industrial development of nuclear power are gaining interest. Hearings of at least six weeks are indicated by the number of requests for appearances already received by the Joint Congressional Committee. Most witnesses who testified at the preliminary hearings last summer (NU, Sept. '53, p. 9) will come back, and many new ones besides.

Before it starts hearings, the Joint Committee wants a chance to study these documents:

AEC DRAFT OF LEGISLATION needed to produce the required revisions. This is the bill around which the hearings and committee discussions will revolve. These AEC proposals were still going the rounds of federal agencies in late December with no firm date set for submission to Congress.

AN INFORMAL REPORT by AEC (as required by Sec. 7b of the Atomic Energy Act) on the "social, political, economic and international effects" of the development of atomic power. Early versions of this report were more comprehensive than had been expected by many government officials. But, again, there was doubt that the report could meet an early January deadline.

FIVE-YEAR PROGRAM of government research and development on industrial power reactors. This schedule, also being prepared by AEC, would indicate the direction of government research in the power-reactor field. A staff report has already been completed.

▶PROPOSALS FOR INDUSTRY PARTICIPATION in AEC's first utility-size nuclear power project (NU, Dec. '53, p. 8) are lagging. Tentative deadline of February 15 has been set for receiving firm offers of private risk capital.

Meanwhile the Government is holding up key decisions such as site selection and architectural planning to give industry wider leeway in joining up.

Main areas for risk capital are:

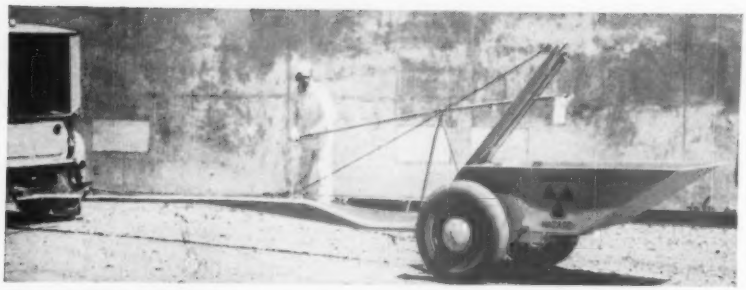
CONSTRUCTION of conventional portions of the 60,000 kw plant such as the generator and turbine along with necessary buildings.

OPERATION of either a part or the whole project. Experience of large electric utilities would fit them for this area of participation. AEC scientists believe utility-trained men are equipped to gather the actual operations data being sought.

Besides gaining first-hand knowledge of nuclear power technology, industry participating in the project could keep a close eye on factors relating to economic feasibility of the government plant. For AEC, industrial participation would ease the federal financial responsibility.

▶ADMINISTRATIVE POLICY figures heavily in the gradually tightening AEC information program (NU, Dec. '53, p. 71). Field information officers raised a ruckus at a recent meeting over the memorandum requiring Washington review of any "nonroutine" news releases. Consideration was given to withdrawal of the memo in favor of a detailed manual for AEC information officers.

Until the manual could be put together, there was no way of knowing whether it would meet the objections raised by the memo, or put a tighter lid on public information releases.



REMOTE-CONTROLLED TRAILER and tongs are used by members of the Health Physics Division of AEC's Idaho Operations Office for handling radioactive materials. Off-center body of trailer is locked in place by a rod. When rod is released, hand winch connected by cable to offset boom dumps trailer. Tongs supported by portable tripod employ jaws knives, or hooks

Council for Nuclear Research, organized under UNESCO auspices at the end of 1951.

The session continued study of plans for a European Institute of Nuclear Research, to be built near Geneva, as soon as the plans are ratified by the governments concerned. So far, only one country, Switzerland, has ratified. The others are expected to sign soon.

Among the technical staff already attached to the council in a permanent manner are: O. Dahl, Norway, director of the proton synchroton group; C. J. Bakker, Netherlands, director of the synchro-cyclotron group; L. Kowarski, France, director of the laboratory group, and N. Bohr, Denmark, director of the theoretical studies group.

AEC Cuts Mound Research, Cancels Spoon River Plant

Progress in research programs and technical improvements in existing production plants have put Atomic Energy Commission projects so far ahead of schedule that construction of the explosives processing and assembly plant on the Spoon River near Macomb, Ill., has been cancelled. In addition, part of the research and development work at Mound Laboratory in Miamisburg, O., has been discontinued.

Personnel at Mound Laboratory, operated by Monsanto Chemicals Co., has been reduced from 610 to about 500. But a subcommittee of the Joint Congressional Committee on Atomic Energy has held hearings on this cutback with unannounced results.

By cancelling the Spoon River plant, AEC will save, in addition to the $26-million engineering and construction costs, about $4-million in start-up cost and $3-million a year in operating costs. Costs of contract termination are expected to reach $2-million. No major construction had been started.

"From the viewpoint of the national interest," the Commission stated, "it is gratifying that the atomic energy program can move ahead at full speed without making the expenditure planned for the Spoon River plant."

Nuclear Power Industry Needs Capital Guarantee

In stating that the unpredictable weapons material market would be out of the question as the main source of income for a nuclear power industry, Wilfrid E. Johnson, general manager of the Hanford plutonium plant operated by General Electric, pointed out that the industry's financial structure is today very similar to that of the utility industry.

Low capital turnover and extremely high investment per employee make a capital guarantee necessary for both.

In addressing the Seattle Chamber of Commerce, Johnson asserted, "I believe the bulk of the industry can be owned and operated by private enterprise and that the economic basis of the industry will be power."

He predicted that the government will buy its plutonium for defense purposes as a by-product of the nuclear power business. He added that the weapons development and manufacturing facilities will probably be retained by the government, but will continue to be operated by contractors.

A large portion of the manufacturing phase of the industry, said Johnson, will be engaged in manufacturing propulsion equipment for the Navy and the Air Force. In addition, the industry "may produce some power plants for merchant marine use," he said.

Johnson explained that the Atomic Energy Act will have to be revised before most of his predictions can come true.

IRE to Discuss Role of Electronics for Reactors

Applications of electronics in the operation of nuclear reactors will be discussed March 24th at a conference sponsored by the nuclear science group of the Institute of Radio Engineers. The meeting, to be held at the Shelton Hotel in New York, will also hear AEC's classification chief, J. G. Beckerley, speak on "Secrecy and the Electronics Engineer."

Nonreactor-electronics progress at the AEC's national laboratories will be covered by: P. R. Bell, Oak Ridge National Laboratory; W. A. Higinbotham, Brookhaven National Laboratory; T. Brill, Argonne National Laboratory; and R. J. Watts, Los Alamos Scientific Laboratory.

L. R. Hafstad, head of AEC's Reactor Development Division, will be the featured luncheon speaker.

Reactor simulators will be the subject of a paper by Kenneth H. Fishbeck, of the Bendix Aviation Corporation. Safety aspects of reactor control circuitry will be covered by T. E. Cole, of ORNL; use of period circuits, by Elmer J. Wade, Knolls Atomic Power Laboratory; and synthesis of nuclear control systems, by Nelson Grace, Westinghouse Atomic Power Division.

Chairman of the sessions will be: Lloyd V. Berkner, president of Associated Universities, Inc.; and W. M. Breazeale, professor of electrical engineering at Pennsylvania State College.

Harwell to Sponsor Isotope Meeting at Oxford in July

Progress in techniques for using radioisotopes will be discussed at a conference arranged by the Atomic Energy Research Establishment, Harwell. The meeting will be held in Oxford, July 19–24, 1954.

An exhibition of instruments and techniques of interest to radioisotope users will be held during the conference. Further details and application forms can be obtained from the Conference Secretary, A.E.R.E., Harwell, Didcot, Berks, England.

Geo-thermal Steam May Be Used to Cut Cost of D_2O

New Zealand has approved the principle of construction of a plant to produce electricity and heavy water by use of geo-thermal steam. Test drill-

ing is underway at Wairakei, north of Lake Taupo on the North Island. This area is noted for its natural-steam resources.

Britain, understood to be considering financing the scheme, would get the heavy water produced.

Presumably, the steam's heat would be used as an economical means of increasing the deuterium concentration in the feed water. This would lead to savings in plant size and operating expense, and thus, heavy water cost would be reduced (NU, Dec. '53, p. 10).

Zirkle Named Chairman of NRC Radiobiology Unit

The National Research Council's Subcommittee on Radiobiology of the Committee on Nuclear Science is now headed by R. E. Zirkle, of the University of Chicago Institute of Radiobiology and Biophysics.

Vice-chairman is Howard J. Curtis of Brookhaven National Laboratory's Biology Division.

Other members of the subcommittee are: H. L. Friedell, Alexander Hollaender, Martin D. Kamen, John Magee, James J. Nickson, Harvey M. Patt, Arthur K. Solomon, and Cornelius A. Tobias.

Liaison members are: Walter D. Claus of AEC's Division of Biology and Medicine; Lt. William B. Looney, (MC) USNR, of the National Naval Medical Center at Bethesda; and Orr E. Reynolds of the Office of Naval Research.

National Research Council representatives to the Subcommittee are: Brian O'Brien, John S. Coleman, R. C. Gibbs, Frank L. Campbell, and Philip S. Owen.

IN BRIEF

• U. S.–college relations. An advisory committee of the National Science Foundation has been set up to study the effects of government support to colleges on their research and teaching functions.

• Biology and medicine contracts. Sixty-nine unclassified one-year research contracts in biology and medicine were awarded by the U. S. Atomic Energy Commission during August–September. Thirty contracts cover biological studies, thirty-two are in the medical sciences, six in biophysics, and one in instrument development.

• Industrial hygiene fellowships. The Oak Ridge Institute of Nuclear Studies is accepting applications for

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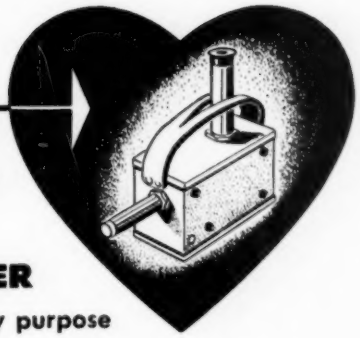
radiation measurement and still growing in versatility

THE VICTOREEN

CONDENSER r-METER

...with a chamber for every purpose



For years the Victoreen Condenser r-meter has fulfilled its designed function as a secondary standard of radiation measurement. The r-meter continues to grow in versatility and reliability—while retaining its world-recognized accuracy and its simplicity of operation. The Condenser r-meter is a compact, portable, battery-operated instrument for the precise measurement of gamma radiation and X-ray dosage in International Roentgens. Detachable ionization chambers are charged in the r-meter, placed in the radiation field, then returned to the r-meter where total exposure in Roentgens may be read.

VERSATILE...IN CHAMBER SELECTION

CHAMBER TUBE DATA

TYPE	MODEL	RADIATION SPECTRUM KeV (effective)	RANGE (r)	MINIMUM ENERGY OF ELECTRONS TO TRAVERSE WALL (KeV)	INTENSITY LIMITS r/SEC	OUR CALIBRATION STANDARD IS
HI-ENERGY X-ray Co_{60} Ra	552 553 554	2000 TO 400 KeV	0–2.5 0–25 0–250	1050 1050 1050	0.1 15.0 40.0	A SECONDARY-STANDARD CHAMBER CALIBRATED AT THE BUREAU OF STANDARDS ON Co_{60} AND Ra*
MEDIUM ENERGY	130 70–5 131 154	400 TO 50 KeV	0–0.25 0–25 0–100 0–250	730 270 330 330	3×10^{-3} 15 25 40	PRIMARY STANDARD AIR CHAMBER OVER THE RANGE 180 TO 25 KV
LOW ENERGY	365	50 TO 20 KeV	0–250	100		PRIMARY STANDARD AIR CHAMBER OVER THE RANGE 180 TO 25 KV
BETA MEASURING	576 577 578	7 MG/CM^2 WALL	0–.25 0–2.5 0–25			NOT CALIBRATED. WALL EQUIVALENT TO EPIDERMIS LAYER OF HUMAN SKIN.

** There is no primary standard for the roentgen above 400 KeV*

ISOTOPE ASSAY CHAMBER MODEL 503

RADIOISOTOPE	SENSITIVITY ON 25r SCALE *
IODINE	2.4 DIV/MIN x MC I–131
GOLD	2.8 DIV/MIN x MC AU–198
PHOSPHOROUS	0.038 DIV/MIN x MC P–32
RADIUM	6.8 DIV/MIN x MG IN.5PT
RADON	7.4 DIV/MM x MC IN 3MM AU

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Gamma Isotope Measurements

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Of Secondary Standards
Of X-ray Equipment
For Military Specifications

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X-ray Machine Shielding
Isotope Shipments
TV Projection Tubes
X-ray Shoe Fitting

STUDY OF BIOLOGICAL EFFECTS FROM TOTAL DOSE

STUDY OF ORGANIC EFFECTS
Food Preservation
Sterilization
Bacteriology
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STUDY OF INORGANIC EFFECTS
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- Two beta-gamma models each with two logarithmic scales:
  Model AGB-50-SR .05-50 mr/hr and .05-50R/hr
  Model AGB-500-SR .5-500 mr/hr and .5-500R/hr
- Built-in calibration source provides accuracy of at least ± 10%.
- Energy dependence—Substantially independent from 75kev. to 1.2mev. (Tested by Nat'l Bur. of Stds.)
- Stable, low voltage circuit with Neher-White ion chamber eliminates such troublesome components as high voltage supply, vibrators, transformers, and high meg resistors.
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- Hermetically sealed, immersion proof, shock mounted, unaffected by temperature, humidity, or pressure variations.

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fellowships for industrial hygiene studies at either the University of Pittsburgh or Harvard University.

• **Health physics fellowships.** Applications are being accepted by the Oak Ridge Institute of Nuclear Studies for a program consisting of nine months of course work followed by three months of field training at an AEC installation. The programs are carried out in three separate programs: at Vanderbilt University and Oak Ridge National Laboratory, at the University of Rochester and Brookhaven National Laboratory, and at the University of Washington and Hanford Works.

• **French-Swedish cooperation.** The Commisariat á l'Energie Atomique has delivered uranium rods for the reactor now being completed in Stockholm by Sweden's Atomic Energy Co. The Swedish company will ship uranium oxide to France.

• **Investment fund.** Common stock is being offered by Atomic Development Mutual Fund, Inc., for investment in "activities resulting from atomic science." Nuclear Development Associates, Inc., White Plains, New York, will be the fund's technical advisor.

• **Research appointments.** Applications for temporary research appointments in biology, chemistry, engineering, medicine, metallurgy, and physics are being accepted by Argonne National Laboratory.

• **NRX reconstruction.** A more powerful Canadian research reactor is expected to become operational very soon. Accident in December, '52, made NRX reconstruction necessary (NU, Jan., '53, p. 76; March, '53, p. 70). No information is available on how many features intended for NRU will be included in new NRX.

• **NRU,** new Canadian research reactor (NU, Feb., '53, p. 82), is scheduled for '55 completion. Unlike NRX, it will use heavy water instead of light water as coolant.

• **Launch sub.** The first nuclear-powered submarine will be launched on Jan. 21st at Groton, Conn. Trial runs will probably occur in late '54. Early tests will determine extent of Navy's future nuclear propulsion.

• **Swedish cyclotron.** A new 200-Mev cyclotron has been completed at the Nobel Institute for Physics, near Stockholm. The high capacity of this cyclotron, the world's largest, has been attained by using oxygen particles instead of hydrogen particles for bombardment.

RAW MATERIALS

• **Sweden.** Full-scale operation has begun at the extraction plant near Örebo in Central Sweden. Large deposits in the area contain about 200 grams of uranium per ton of shale. Present plans include installations for the production of pure uranium from these deposits.

• **Australia.** Uranium oxide has been refined in Australia for the first time by a pilot plant at Radium Hill in South Australia.

Stocks of ore are being assembled for treatment in a large refining plant of U. S. design. The plant will be erected near large uranium deposits at Rum Jungle in the Northern Territory. Commercial-scale production is expected to start in about six months using the plant shipped from the United States by the U. S. Atomic Energy Commission as part of a plan to cooperate with Australian authorities in the exploitation of uranium deposits. Plant cost will be paid by uranium shipments to the U. S.

NEWSMAKERS

S. E. Beall has been appointed project engineer in charge of experimental homogeneous reactors at Oak Ridge National Laboratory. He will be responsible for the program leading to reconstruction of HRE, including coordination of reactor analysis, design and engineering development work, and also for the continuation of the experimental program of the HRE.

Donald F. Mastick, formerly technical assistant in the military application division of the Atomic Energy Commission, has become coordinator of special projects for General Precision Equipment Corp., New York, N. Y.

William R. Hewlett, vice president of Hewlett-Packard Co., has been elected president of the Institute of Radio Engineers. He succeeds **James W. McRae,** president of Sandia Corp. and vice president of Western Electric Co.

Maurice M. Shapiro, head of the cosmic ray branch of the Naval Research Laboratory, has been named superintendent of the nucleonics division. He succeeds **F. N. D. Kurie,** who has become technical director of

the U. S. Navy Electronics Laboratory in San Diego.

Alexander T. Shulgin has been named director of the radiochemical division of Bio-Rad Laboratories, Berkeley, California. He was formerly a member of the biochemistry department of the University of California.

William E. Shoupp has been appointed assistant division manager in charge of development for the Westinghouse Electric Corporation's Atomic Power Division.

Frederick H. Warren is now a consulting engineer on uses and developments in the atomic energy field. He had been deputy director of the construction and supply division of A.E.C.

MEETINGS

Jan. 25-27: High-Energy Nuclear Physics Conference, University of Rochester, Rochester, New York. Informal discussion of latest experimental results and their interpretation by a representative group of active research workers in the field of high-energy physics. The conference will be directed by Joseph B. Platt. It will be sponsored by the University of Rochester, the National Science Foundation, and a group of Rochester industries.

March 24: Institute of Radio Engineers National Convention. See story on page 74.

June 20-23: American Institute of Chemical Engineers' Conference on Nuclear Engineering; University of Michigan, Ann Arbor, Mich. Will focus on role of chemical engineering in applications of nuclear energy with emphasis on power production, education for nuclear engineering, and fission product utilization. The conference is under the direction of Donald L. Katz, chairman of the university's chemical and metallurgical engineering department. (NU, Aug. '53, p. 64).

July 13-17: Conference on Experimental and Theoretical Nuclear Physics; University of Glascow, Glascow, Scotland. Topics to be discussed include: Nuclear forces, properties of nuclear energy levels, beta- and gamma-ray transitions, pi mesons and heavy mesons. Concentration will be on results and ideas rather than on particular experimental techniques.

July 19-24: Harwell Radioisotope Conference; see story on page 74.

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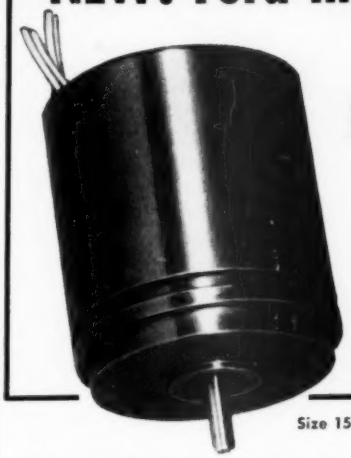
TELESYN® RESOLVER



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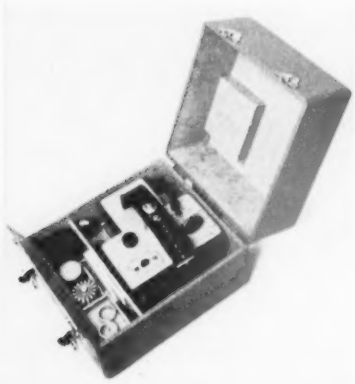


Alpha-Beta Dose Meter

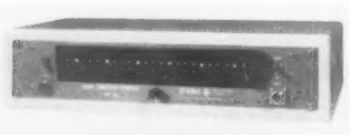
Landsverk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif. The model L-76 quartz-fiber meter measures α- and β-rays down to a fraction of radioactive background. A built-in timer stops the fiber image on the microscope reticle; timer can be set to read directly beta contamination of food and water by fission products directly in terms of acceptable 10- or 30-day emergency levels of the FCDA. Liquid samples are supported in metal containers below the ionization chamber. Accessories included are filters, planchets, planchet holders, aluminum dishes, and instruction book. (P-1)

Mobile X-Ray Unit

Philips Electrical Ltd., Century House, Shaftesbury Ave., London, W.C.2, England. The D.X.5 mobile X-ray unit, fitted with a Mullard shockproof rotating anode X-ray tube, has a rating of 100 ma at 100 kv. Effective focal spot is 1 mm. Tubestand is equipped with a compensated spring counterpoise. Potential is said to be constant irrespective of load. Timer circuit enables exposure factors to be determined before exposure is made; time switch has 0.06–8 sec range. (P-2)

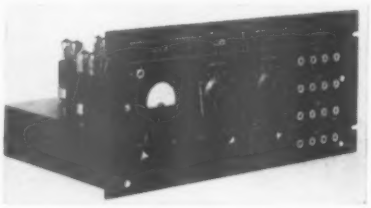
Radiation Thickness Gage

Instruments, Inc., Tulsa, Oklahoma. The Rad-O-Thik measures wall thickness of pipe without access to the inside of the pipe and, under certain conditions, without removing the pipe from service. The source is $^1/_{1,000}$ gm radium salt; the detector is a G-M tube. Counting-rate meter is calibrated in inches of steel. One unit may be used to measure any pipe size between 2 and 12 in. (P-3)



Glow-Transfer Counter

Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass. The model 162A glow-transfer counter has a maximum capacity of 1,000,000 counts with a speed range of 0–5,000 cps. Counting, indication, and transfer is done by the cold-cathode tubes. Input can be positive or negative pulses or sine waves of 4–60 volts, depending on control setting. A jack provides for remote-control operation. Unit may be used as a counter or push-button resettable register. (P-4)



Analog Stimulus Generator

George A. Philbrick Researches, Inc., 230 Congress St., Boston 10, Mass. The model CS analog stimulus generator is for use in high-speed, repetitive analog computing systems. Fixed time base of 20 cycles/sec affords a 40-msec computing interval. Three internally synchronized signals hold a system stabilized prior to stimulation, provide a linear time-base covering the 50-msec interval, and provide a pulse adjustable from 0 to 50 volts, positive or negative, which may be retracted to form a square pulse of 0–30 msec width. Binary reversing system optionally alternates between positive and negative step stimuli on a 10-cycle base. (P-5)

Photomultiplier Tube

Radio Corporation of America, RCA Victor Div., Harrison, N. J. The 6342 photomultiplier tube, designed for scintillating counting, covers the range 3,000–6,200 Å with maximum at 4,000 Å. Semitransparent cathode, $1^1/_2$-in. diameter, is on inner surface of flat face of tube having minimum diameter of $1^1/_2$ in. At 1,500 volts, maximum anode-supply voltage, current multiplication is 600,000. For input pulse with rise time ≤ 1 mμsec, and

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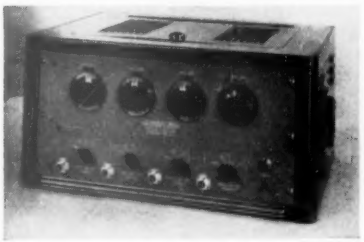
measured between 10 and 90% magnitude points when supply voltage is 1,500 volts, rise time of pulse at anode is 5 mμsec. (P-6)



Coincidence Analyzer

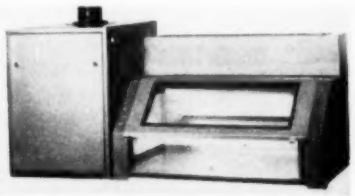
Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. The model 412 coincidence-anticoincidence analyzer has resolution ranges said to be fixed for the life of the instrument; it will not go out of calibration when a tube is changed or repairs made. Input pulse is −50 to +100 volts, or any combination; resolution ranges are 0.25, 0.5, 1 and 2 μsec; channel output is 25 volts, negative. Channel 1 may be used in anticoincidence with any other one or all of the other 3 channels. Coincidence output is 25 volts, negative; anticoincidence output is 25 volts, negative. Channel deadtime is <10 μsec. (P-7)

Remote Electronic Thermometer

Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio. The Tele-Thermometer, a remote-reading electronic thermometer, operates in the range 68–105° F, with temperature read direct from a dial calibrated in Centigrade and Fahrenheit. Readings are accurate to ±0.25° C and can be calibrated to ±0.1° C. A thermistor probe is at the tip of a 6-ft, plastic-encased wire. Power is supplied by a flashlight D battery. Units may be provided in multiple-channel models for use with series of probes. (P-8)

Data Recorder

Hastings Instrument Co., Inc., Superhighway and Pine Ave., Hampton, Va. This instrument records in sequence three variables at 20 different points, utilizing any sensing element providing an electric output. Unit can be set to different combinations of manual or automatic operation; it can be set to record as many as 60 variables. Time to record 60 measurements is 2 min; symbols identify variable measured and point of measurement. (P-9)



Dust-Proof Cabinets

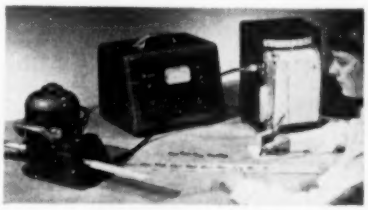
The Baker Co., Inc., Maplewood, Me. The model 12 bench-type dust and germ-proof cabinet, drawing air through an electronic cleaner, removes particles below 1/100 micron. Workspace is 40 × 24 in.; opening is 32 × 6 in. Clean air forced into workspace maintains pressure barrier against contamination through opening. Two 30-watt fluorescent lamps illuminate interior; ultraviolet lamps are also available. (P-10)

Decade Counter

Decade Instrument Co., Box 153, Caldwell, N. J. The model 100–1 decade counter provides square waves at 1/10 of the input frequency. Another output circuit furnishes positive or negative pulses with rise time of 0.25 μsec at an amplitude of 40 volts. Input requirements are 100 mv, 100 cycles to 1.2 Mc. (P-11)

Decade Counter Tube

Amperex Electronic Corp., 230 Duffy Ave., Hicksville, N. Y. The type E1T decade counter tube gives count indication by a rectangular luminescent spot appearing opposite figures 0 to 9 on the circumference of the bulb. It operates on a 300-volt supply. The tube can be mounted in any position except with the tube horizontal and fluorescent screen downward. Socket is the Amperex duodecal type S-13264 or equivalent. (P-12)



Radiochromatogram Scanner

Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The Actigraph automatic scanner for paper radiochromatograms consists of a strip feeder, lead shield that contains mica-end-window counter and collimating slit, analytical counting-rate meter, and an Esterline-Angus chart-type recorder. The chromatogram is taped to a metal strip table, passed through the lead shield, and through the rollers of the strip feeder. Movement of the strip is synchronized with the recording chart. Chart and strip may be set to

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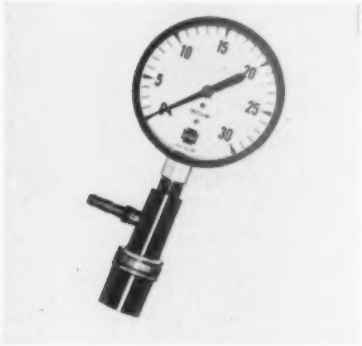
one of eight speeds from 0.75 to 360 in./hr. Special tables permit operation as a simple sample changer or with absorbers to produce a characteristic absorption curve. (P-13)

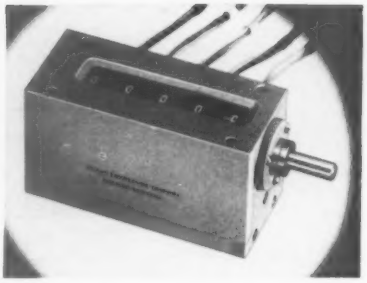


Radioactivity Air Sampler

Tracerlab, Inc., 130 High St., Boston 10, Mass. The BI-101 radioactivity laboratory air sampler consists of a type 316 stainless-steel filter holder, vacuum gage, and vacuum hose attachment. The holder takes a 22-mm-diameter filter paper, which can be mounted on a 1-in. planchet for counting. Filter is supported by 16 × 16 mesh stainless steel wire allowing an active $^3/_4$-in.-diameter filter area. Vacuum reading of 16 in. Hg on gage indicates a flow rate of 4 ft^3/min, using Hollingsworth & Vose H-70 (0.009-in. thick) filter paper. (P-14)

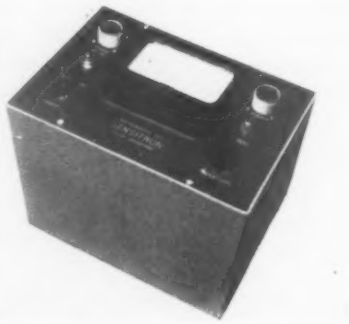
Electric Timers

Atomic Center for Instruments & Equipment, Inc., 489 Fifth Ave., New York 17, N. Y. These timers have ranges of 0.1–10,000 sec and 0.01–1,000 min read on an odometer-type clock. They are driven by a synchronous electric motor requiring no oiling. Starting and stopping losses are self-compensating. Timers can be reset to zero by one turn of resetting knob. (P-15)



Decade Counters

Wright Engineering Co., 180 E. California St., Pasadena 1, Calif. The Digipot and Digicon are mechanically-geared decade counters. Potentiometers on each digit-wheel of the Digipot provide voltage division proportional to the number indicated by the mechanically coupled wheels. The Digicon is designed with 10-ma-rated contacts in 10 positions around each decade of the counter wheels. The units are available with 3 or 5 decades. Gearing allows for reduced transfer torque of 1.5 in.-ounces for all digits in both forward and reverse directions. Stepper motors for actuation of the counters are available. (P-16)



Density and Level Indicator

Instruments, Inc., 122 N. Madison, Tulsa, Okla. The Densitron, a radiation-type level and density indicator, comprises a small amount of radium salt in a lead-shielded container (collimated for emission in one direction), a 6-lb detector unit, and an 18-lb master unit. It is claimed that the source can be safely handled by one man for 8 hr every day. Portable and panel-mounted units are available. (P-17)

Filter Membrane

Lovell Chemical Co., Watertown 72, Mass. The Millipore filter membrane is made in sheets of 140 microns thickness with about 50 million pores per cm^2. Particles of 0.5 micron or greater are quantitatively concentrated. The material is of uniform index of refraction, transparent when the pore volume is filled with a clear liquid of proper index. Because of surface collection, as opposed to penetration into the depth of the filter, radiation absorption is said to be minimal. (P-18)

Beta-Absorption Gage

Central Scientific Co., 1700 Irving Park Rd., Chicago, Ill. The Beta Ray H/C Meter, utilizing a Sr^{90} source and ionization-chamber detector, is designed to measure the percentage hydrogen and H/C ratio in petroleum, but is said to offer other application possibilities. Analysis time is claimed to be reduced from the 4 hr necessary for the combustion-train method to 5 min. Individual determinations can be made with a statistical probable error of 0.02 weight% hydrogen. No stray radiation is said to be measurable on a 0–25 mr/hr meter. The unit uses two beams and two ionization chambers; one beam traverses a fixed absorber and the other the 10-cm^3 sample cell and an adjustable absorber. (P-19)

Cathode-Ray Tubes

Radio Corp. of America, Tube Dept., Harrison, N. J. The 5AB series of 5-in., flat-face, cathode-ray tubes utilize electrostatic focus, electrostatic deflection, and postdeflection acceleration; tubes differ only in phosphor used. The 5ABP1, for wide-band vertical amplifiers or general-use high-

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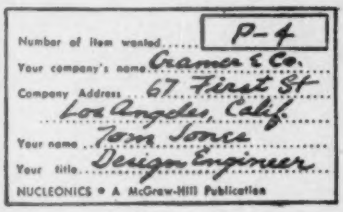

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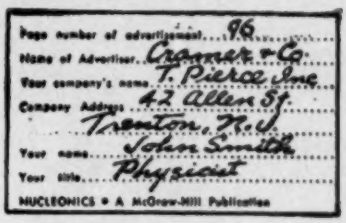

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After each new products review, there appears a number (such as P-1). If you wish further information on any item, place the number that follows it in the box provided on the first line in the BOTTOM postcard to the right. As stated above, all the remaining information must also be filled in.

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After each literature review, there appears a number (such as L-1). If you wish to receive any literature item, place the number following it in the box provided in the BOTTOM postcard. Be sure to completely fill in each request.

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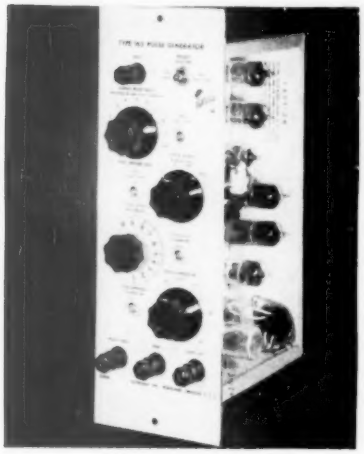
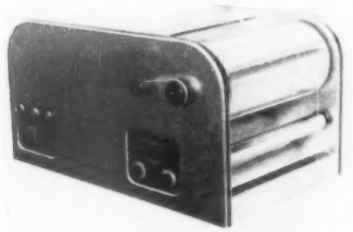
intensity traces, can be operated with scanning frequencies down to 20 cps without excessive flicker; emission is 4,800–5,900 Å. The 5ABP7, for applications requiring phosphorescence persistence of several minutes, can be operated with scanning frequencies down to 30 cps or lower with yellow filter; emission is 4,200–6,600 Å. The 5ABP11 is a short-persistence type for photographic recording. (P-20)



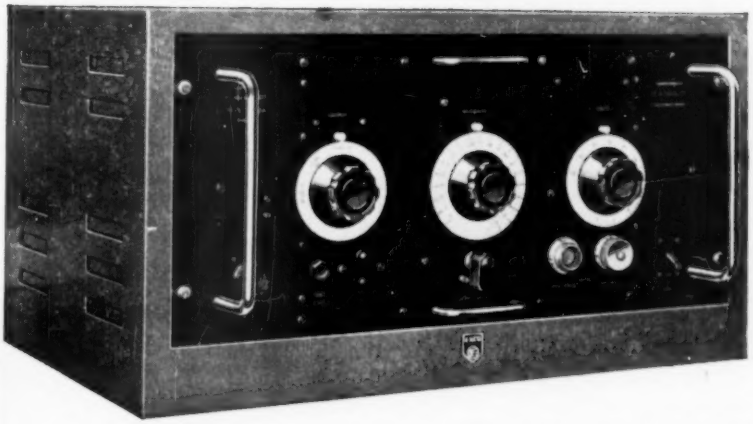
Rectangular-Pulse Generator

Tektronix, Inc., Box 831, Portland 7, Ore. The type 163 pulse generator supplies rectangular pulses of <0.2-μsec rise time when triggered by either a positive pulse or a negative-going sawtooth from an external source. Output is positive, 0–25 volts peak to peak; positive gate is 25 volts fixed amplitude. Duration is 1–10,000 μsec. When triggered by sawtooth, output may be delayed 0–100% of sawtooth duration. Decay time is 0.2 μsec; overshoot adjustable to zero. (P-21)



Oscillogram Processor

Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif. The 23-109 oscillogram processor completely processes and dries standard recording papers, up to 12 in. wide, at speeds exceeding 10 ft/min. Darkroom facilities and external water



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Specification

Output Current: 1 mA max. between 500 and 1500 volts. 0.5 mA max. between 1500 and 3000 volts.

Output Voltage: Continuously variable between 500 and 3000 volts positive or negative, with an accuracy of ± 1% of dial reading.

Ripple and Pulse content. Ripple, Noise and Spurious pulses have a maximum level of 500 micro-volts at 3000 volts H.T. A high impedance output socket is provided, at which this figure is reduced to less than 100 micro-volts.

Stability & Resetting Accuracy. Stability for mains variations of ± 10% is ± 0.05%. Drift due to all other causes is within the following limits:

1 hour ± 0.05%
100 hours ± 0.1%
1000 hours ± 0.2%

Mains Input. 110–120 and 200–250 volts A.C., 40–60 c.p.s.

Consumption. 115 watts.

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Here's a new *automatic* scaler, based on proven circuits, yet incorporating the latest engineering advances. The Model 183 "Count-O-Matic" accurately counts the pulses from a G-M or scintillation detector, measures the length of time required to accumulate a predetermined number of these pulses, and supplies 500 to 2500 volts for the detector

The instrument can be used as a conventional scaler with the counting time manually controlled by the operator, or exclusive "Count-O-Matic" and scale selector controls permit 21 *predetermined count* settings from 40 to 256,000 counts. In addition, the counting time can be preset for periods ranging from 2 seconds to 60 minutes by the use of Model T1 Dual Timer. The scaler will then indicate the number of disintegrations recorded during this time interval.

Total count is indicated on an easily read register, while the built-in timer automatically indicates elapsed counting time to 9999.99 minutes. A single switch operates electrical reset of the register, timer, and interpolation lamps.

Model 183 should be chosen whenever automatic Geiger or scintillation counting is advantageous. It is ideal for counting a large number of samples routinely, or may be connected directly to Model C-110 Automatic Sample Changer. Further information on this scaler will be gladly sent on request.

Nuclear Instrument & Chemical Corporation, 235 W. Erie St., Chicago 10, Ill.

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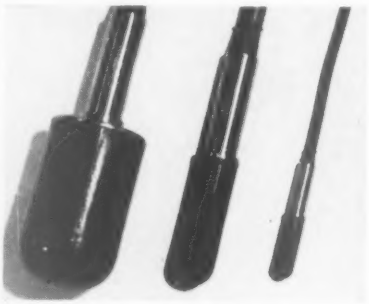
supply are not needed. The unit is portable, 17 × 31 × 18 in. Stabilizer solution used eliminates the washing procedure. Magazine has 250-ft capacity; several magazines may be loaded at one time. Solutions are thermostatically maintained at 100° F; drying-drum temperature is adjustable. Cumulative footage processed is shown on indicator. (P-22)

Thermal Switch

Control Products Inc., Sussex St., Harrison, N. J. The type ASA-21-2 high-temperature thermal switch is designed for applications up to 2,000° F. It has maintained set calibration for 100 hr at 1,500° F with a variation of 10° F. It is claimed to withstand any degree of overshoot or undershoot up to the ability of the metal to stand the temperature rise. It is available normally open or normally closed. (P-23)



Pressure Transducers

Atlantic Research Corp., Electromechanical Div., Alexandria, Va. The models BC-10, BC-30, and BC-50 barium titanate pressure transducers are designed as transient pressure pickups in liquid and gaseous systems. The gages produce voltage responses up to 0.6 volts/psi, flat over frequency ranges of 3 cps to 75 kcps, 1 cps to 40 kcps, and 0.5 cps to 30 kcps, respectively. Sensitive elements are hermetically sealed and covered with Neoprene sheath. Input resistances are maintained above 500 megohms, d-c. Models are said to have withstood transient pressures of 10,000 psi and static pressures in excess of 5,000 psi. (P-24)

Paper Electrophoresis Cell

Matthew Laboratories, 345 Nepperhan Ave., Yonkers 2, N. Y. The model PC 101 paper electrophoresis cell, for separation of mixtures of charged macromolecules, is constructed of clear, solvent-welded acrylic plastic. As many as five 1-in. strips may be run simultaneously. (P-25)

Electronic Decimal Calculator

International Business Machines Corp., 590 Madison Ave., New York 22, N. Y. The Magnetic Drum Calculator consists of a magnetic-drum unit with electronic calculating components, input and output unit, and a converter. It utilizes the stored-program concept of the IBM 701. Answers are supplied using the punched-card system. It has up to 20,000 memory positions and can accept as many as 2,000 individual operating instructions. The program may be entered automatically from punched cards or manually from the operator's console; input rate is 200 cards a minute, and separate output is 100 cards a minute. (P-26)

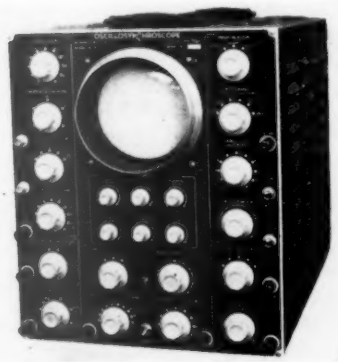
Rack-Mounted Oscillograph

Allen B. Du Mont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N. J. The type 304-AR rack-mounted oscillograph incorporates a flat-faced type 5ADP tube. Voltage reading range

on a 4-in. scale is 0.10–1,000 volts, full scale. Frequency response is flat at d-c and extends to 300 kc, 50% down. The screen is calibrated by a push-button control on the operating panel, which applies a standardizing potential to the screen. (P-27)

Pulse Generator

Wang Laboratories, 296 Columbus Ave., Boston 16, Mass. The Confluxer constant-charge pulse generator can be used as a frequency meter, electronic tachometer, or digital-to-analog converter. Input waveform with rise time as slow as 0.1 sec is said still to insure proper operation. Minimum input is 10 volts. Resolution time permits full charge per pulse if pulses generated are more than 15 μsec apart. Output pulse rating is 200 volt-μsec. Normal operation gives pulse voltage of 70-volt peak and 3-μsec pulse duration. Minimum output load is 2,500 ohms; linearity is 0.2%. (P-28)

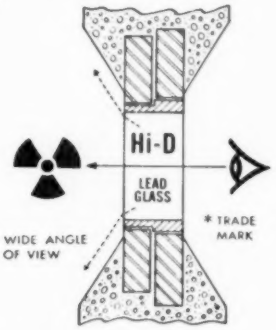


Oscillosynchroscope

Browning Laboratories, Inc., 750 Main St., Winchester, Mass. The model OL-23 oscillosynchroscope provides 4,000-volt accelerating potential, vertical amplifier bandwidth flat from

Hi-D*

LEAD GLASS WINDOWS IN CONCRETE WALLS



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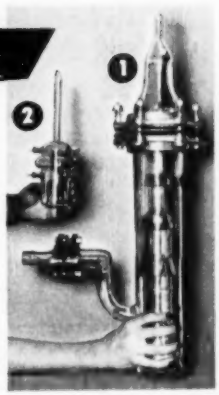

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RAYCHRONIX

Radioactive Products, Inc.
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Please send data on your Scaler and Computer

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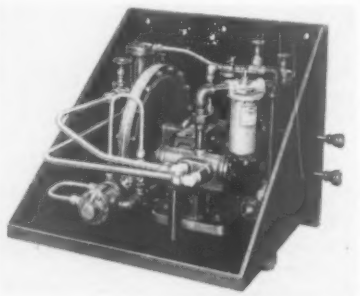
5 cycles to 10 Mc with 0.15-volt sensitivity, peak to peak, per in., and triggered or recurrent sweeps from 0.1 μsec/cm to 0.011 sec/cm. Built-in generator produces output triggers of 50–5,000 pps; continuously variable delay circuit allows sweep to be delayed from triggering source by 5–10,000 μsec under any triggered condition. Synchronization of recurrent, triggered, or delayed triggered sweeps may be from any waveshape. (P-29)



Nonreturn Valve Operator

Askania Regulator Co., 240 E. Ontario St., Chicago 11, Ill. This nonreturn valve operator makes a hydraulically operated nonreturn or check valve of a simple butterfly valve. Utilizing the pressures applied to upstream and downstream diaphragms, the regulator operates the nonreturn valve to maintain a constant low differential pressure across the valve. A reversal of pressure causes the valve to close. The operator is claimed to have a high power output and to control large, tight-closing valves, and to allow low permanent pressure loss through the valve. (P-30)

Wide-Band D-C Amplifier

Furst Electronics, 3322 W. Lawrence Ave., Chicago 25, Ill. The model 220 wide-band d-c amplifier is designed to

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increase the sensitivity of cathode-ray oscilloscopes with extended low-frequency response and can be used to extend the range of other instruments when unusually low frequencies are encountered. A cross-coupled circuit provides phase-inversion for equal results with balanced or unbalanced input signals. When two different signals are applied to the input terminals, the unit acts as a differential amplifier. Maximum gain is adjusted to about 100; input attenuators reduce this gain to approximately 10 and 1 (40, 20, and 0 db). Output impedance is 250 ohms, and 120 ohms, push-pull. (P-31)

INDUSTRY NOTES

▶**Radiation Detection Co.,** Station A, Box 155, Palo Alto, Calif., has changed its name to **Radiation Protection Div., Industrial Health & Hygiene Associates,** with no change in address. Company policy is unaffected.

▶**Fischer & Porter Co.,** Hatboro, Pa., has created a Special Products Division for development of special instruments and instrument components to contract specifications. Mr. Edward H. Muhleisen is manager of the new division.

▶**Medical-Electronics Development Co.,** Box 443, Great Neck, N. Y., is now prepared to accept projects in the fields of medicine, physiology, biology, and related sciences where special electrical instrumentation may be required.

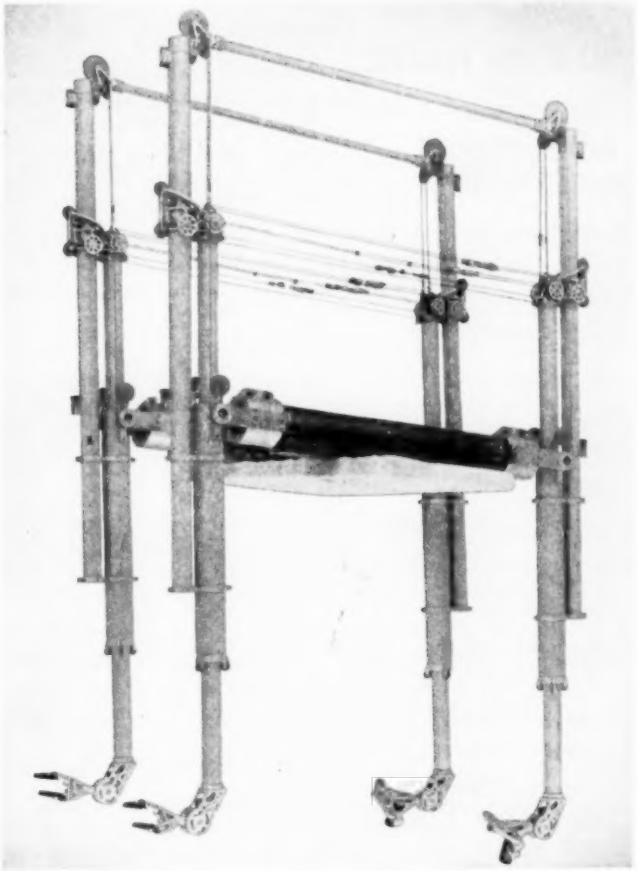
▶**Frederick H. Warren,** formerly deputy director, AEC Division of Construction and Supply, announces the opening of a consulting engineering practice devoted primarily to atomic development services. Address is 1518 K Street, N. W., Washington 5, D. C.

▶**Advanced Scientific Techniques Research Associates,** Box 163, Milford, Conn., has been formed to offer research and development services. Fields of interest are nucleonics, automatic controls, physical chemistry, fluid handling, and thermodynamics, as well as routine engineering work.

LITERATURE AVAILABLE

Water filters. Catalog 300 gives data on sump and line-type filters. *Marvel Engineering Co., 625 W. Jackson Blvd., Chicago 6, Ill.* (L-1)

Radiation detection equipment. Catalog 15 gives data on electronic equipment, counter tubes, scintillation equipment, health instruments, glass apparatus, special chemicals and gases,



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and thin films. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.* (L-2)

Corrosion-resisting valves. Bulletins A and B illustrate and give data on needle valves and safety and relief valves, respectively. *Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.* (L-3)

Panel meters. Specifications of $1\frac{1}{2}$-in. round and square meters are given in model 112 and model 120 bulletins. *DeJur Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N. Y.* (L-4)

Electronic system design. "Ideas-Techniques-Designs" provides data and planning sheets for "unitizing" equipment. *Alden Products Co., Dept. HB, Brockton, Mass.* (L-5)

Cleaning solvents. Data chart lists cleaning and degreasing solvents having low flammability. *John B. Moore Corp., Box 3, Nutley 10, N. J.* (L-6)

Thermometer specifications. Data sheet gives recommended specifications for fractional-degree and general laboratory-grade thermometers. *Scientific Apparatus Makers Association, 20 N. Wacker Dr., Chicago 6, Ill.* (L-7)

Magnetic impulse counter. Folder describes impulse-storing and marking device. *Kellogg Switchboard and Supply Co., 79 W. Monroe St., Chicago 3, Ill.* (L-8)

Plane-grating spectrograph. Catalog EB-10-53 describes 3.4-meter spectrograph. *Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.* (L-9)

Speed reducers. Data sheet no. 10 & 11 describes "bantam-size" speed reducers rated at $\frac{1}{10}$ and $\frac{1}{20}$ horsepower. *Metron Instrument Co., 432 Lincoln St., Denver 9, Colorado.* (L-10)

Water demineralizing. Bulletin 5800 discusses principles and uses of ion-exchange materials. *Cochrane Corp., 17th St., Philadelphia 32, Pa.* (L-11)

Radioactivity dosimeters. Bulletin G-10 gives data and price list of quartz-fiber detection equipment. *Landswerk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif.* (L-12)

Control boards. Bulletin 700 describes instrument and control units. *Continental Electrical Equipment Co., Box 1055, Cincinnati 1, Ohio.* (L-13)

Miniature gage-pressure potentiometer. Brochure 3553 gives specifications on potentiometers for the ranges 0–100 to 0–5,000 psi. *Bourns Laboratories, Dept. NL, 6135 Magnolia Ave., Riverside, Calif.* (L-14)

Stop watches and chronographs. Catalog describes watches having nonbreakable coil spring mechanism. *Herman H. Sticht Co., 27 Park Place, New York 7, N. Y.* (L-15)

Laboratory items. Bulletin describes pipette rotor, stainless steel and polyethylene laboratoryware, etc. *A. S. Aloe Co., Aloe Scientific Div., 5655 Kingsbury, St. Louis 12, Mo.* (L-16)

Frequency meters. Meters in ranges from 900 to 2,550 Mc are described. *Frequency Standards, Asbury Park, N. J.* (L-17)

Hydraulic pumps. Selection data for dual-vane hydraulic pumps are given in bulletin DP-300. *The New York Air Brake Co., Dudco Div., 1700 E. Nine Mile Rd., Hazel Park, Mich.* (L-18)

Water demineralizers. Bulletin 126 describes mixed-bed demineralizers with capacities of 50–2,500 gal/hr. *Barnstead Still & Sterilizer Co., 222 Lanesville Terrace, Forest Hills, Boston 31, Mass.* (L-19)

Refrigeration cabinets. Mechanically refrigerated, 0.8-ft^3 units for operation to −100° F described in bulletin. *Refrigeration Systems, Inc., Hudson Bay Div., 646 W. Washington Blvd., Chicago 6, Ill.* (L-20)

Laboratory apparatus. The 19th edition of "What's New for the Laboratory" includes chromatographic equipment, rapid-scanning spectrophotometer, and ultraviolet lamps. *Scientific Glass Apparatus Co., Bloomfield, N. J.* (L-21)

Nondestructive testing. Bulletin 32 describes ultrasonic, hydraulic, hardness, magnetic, and micrometer testing instruments. *J. W. Dice Co., 1 Engle St., Englewood, N. J.* (L-22)

Laboratory demineralizer. Permanent cartridge water demineralizer providing up to 10 gal/hr is described in brochure. *Penfield Mfg. Co., Inc., 19 High School Ave., Meriden, Conn.* (L-23)

Frequency converter. Circular E11 describes 400-cycle supply. *Georator Corp., Manassas, Va.* (L-24)

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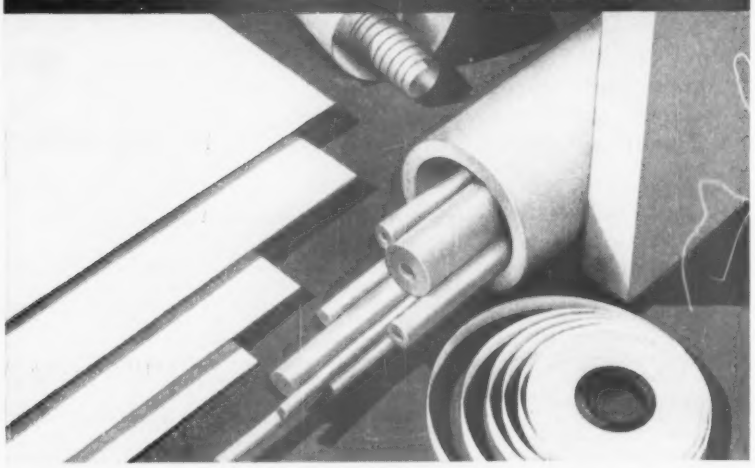

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INDEX TO ADVERTISERS

JANUARY, 1954

Allen-Bradley Co. 59
Atomic Instrument Co. Third Cover
Automatic Switch Co. 65
Berkeley Division, Beckman Instruments Inc. 69
Bersworth Chemical Co. . . . 83
Central Research Laboratories, Inc. 85
Chicago Standard Transformer Corp. 63
Consolidated Engineering Corp. . . . . Second Cover
Dale Products, Inc. 66
Detectron Corp., The 64
Eitel-McCullough, Inc. 83
Ekco Electronics Ltd. 81
Ford Instrument Co. Fourth Cover
77
General Electric Co. 4
International Resistance Co. 3
Jordan Electronic Sales, Inc. 71, 76
Keleket Instrument Div. 64
Kollmorgen Optical Corporation 58
McGraw-Hill Book Co., Inc. Technical Wiring Service . 84
Minneapolis-Honeywell Regulator Co., Industrial Div. 67
National Radiac Inc. 86
Nuclear Instrument & Chemical Corp. 82
Penberthy Instrument Co. . . 83
Radioactive Products, Inc. . . 84
Radio Shack Corp. 77
Special Screw Products Co. . 70
Stokes Machine Co., F. J. . . 2
Technical Service Corp. 83
United States Gasket Company 88
United States Radium Corp. . 64
Victoreen Instrument Co. . . . 75

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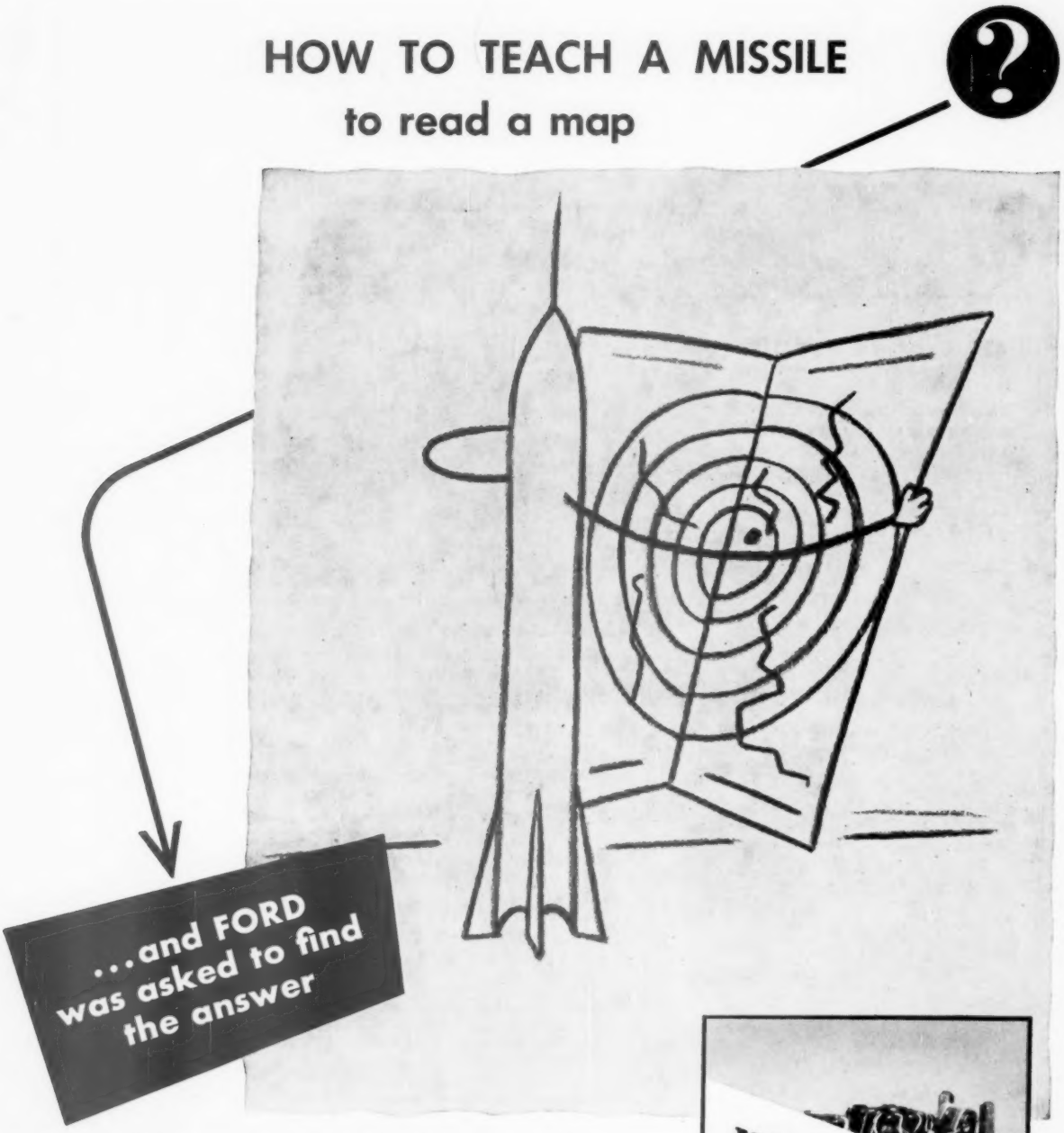

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